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# SPACE SHUTTLE EXTERNAL INTERFERENCE HEATING TEST

William K. Crain and Kenneth W. Nutt

Calspan Field Services, Inc.



December 1982

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This report has been reviewed and approved.

J. T. Best

J. T. BEST
Aeronautical Systems Branch
Deputy for Operations

Approved for publication:

FOR THE COMMANDER

J. M. Rampy

JOHN M. RAMPY, Director
Aerospace Flight Dynamics Test
Deputy for Operations

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Interference heating data were obtained on the 0.0175 scale 60-OTS Integrated Integrated Space Shuttle Vehicle in the AEDC Aerothermal (M=4) Tunnel C Facility. The data were obtained at $M = 4.0$, $Re/ft = 0.4 \times 10^6$ to $6.6 \times 10^6$, $TW/TT \approx 0.3$ to $0.8$ at angles of attack of -5 to +5 degrees and -3 to +3 degrees angle of sideslip. The purpose of the tests was to obtain External Tank Interference heating data at higher total temperatures (lower TW/TT) for assessment of the validity of interference heating data previously obtained in the AEDC Tunnel A. A second objective was to obtain data at conditions comparable to STS1-4 flight data.

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CONTENTS


| | | Page |
|---|---|---|
| | NOMENCLATURE | 2 |
| 1.Ø | INTRODUCTION | 6 |
| 2.Ø | APPARATUS | |
| | 2.1 Test Facility | 7 |
| | 2.2 Test Article | 7 |
| | 2.3 Test Instrumentation | 8 |
| 3.Ø | TEST DESCRIPTION | |
| | 3.1 Test Conditions | 9 |
| | 3.2 Test Procedures | 9 |
| | 3.3 Data Reduction | 10 |
| | 3.4 Uncertainty of Measurements | 14 |
| 4.Ø | DATA PACKAGE PRESENTATION | 14 |
| | REFERENCES | 15 |


APPENDIXES


I. ILLUSTRATIONS

Figures

| | | |
|---|---|---|
| 1. | Tunnel C Mach 4.Ø Configuration | 17 |
| 2. | The 6Ø-OTS Integrated Space Shuttle Vehicle | 18 |
| 3. | Model Installation in Aerothermal Tunnel C | 23 |
| 4. | External Tank Instrumentation | 25 |
| 5. | SRB Instrumentation | 31 |
| 6. | Tunnel C Model Cooling Apparatus | 36 |
| 7. | Comparison of External Tank Heating Data from Present Test, IH-85, IH-72 and Theory at M = 4.00 | 37 |

II. TABLES

Table

| | | |
|---|---|---|
| 1. | Data Transmittal Summary | 39 |
| 2. | Measurement Uncertainty | 40 |
| 3. | Instrumentation and Constants | 42 |
| 4. | Schmidt-Boelter Gage Calibration Constants | 46 |
| 5. | Run Summary | 47 |
| 6. | Photographic Summary | 49 |

III. REFERENCE HEAT-TRANSFER COEFFICIENTS ........... 50

IV. SAMPLE TABULATED DATA

| | | |
|---|---|---|
| 1. | Thin Skin Thermocouple | 52 |
| 2. | Schmidt-Boelter Gage | 53 |

## NOMENCLATURE

| | |
|---|---|
| $a_1, a_2, a_3$ | Denote constant terms used to calculate R |
| ALPHA | Model angle of attack, deg |
| ALPHA-SECTOR, $\alpha_s$ | Tunnel sector angle, deg |
| b | Model wall thickness, ft |
| BETA | Model angle of sideslip, deg |
| c | Model wall specific heat, Btu/lbm-$^{\circ}$R |
| C.R. | Center of rotation, axis about which model is pitched in the tunnel |
| $C_1$ | Schmidt-Boelter calibration constant, mv/Btu/ft$^2$-sec, Table 4 |
| DELTBF | Body flap deflection angle, deg |
| DELTAE | Elevon deflection angle, deg |
| DELTSB | Speed brake deflection angle, deg |
| DTW/DT | Derivative of the model wall temperature with respect to time, $^{\circ}$R/sec |
| E | Schmidt-Boelter Gage output, mv |
| GAGE NO | Schmidt-Boelter Gage identification number |
| H(TR) | Heat-transfer coefficient based on TR, $\frac{\text{QDOT}}{\text{TR-TW}}$, $\frac{\text{Btu}}{\text{ft}^2\text{-sec}^{\circ}\text{R}}$ |
| H(TT) | Heat-transfer coefficient based on TT, $\frac{\text{QDOT}}{\text{TT-TW}}$, $\frac{\text{Btu}}{\text{ft}^2\text{-sec-}^{\circ}\text{R}}$ |
| H(Ø.95TT) | Heat-transfer coefficient based on Ø.95TT $\frac{\text{QDOT}}{(0.95\text{TT})\text{-TW}}$, $\frac{\text{Btu}}{\text{ft}^2\text{-sec-}^{\circ}\text{R}}$ |
| (Hi/Hu) | Ratio of the local heat-transfer coefficient on the External Tank in the interference flow field; i.e., with orbiter, SRB's divided by the local heat transfer coefficient for the tank alone. |

| | |
|---|---|
| H (RTT) | Heat-transfer coefficient based on RTT $\frac{QDOT}{RTT-TW}$, $\frac{Btu}{ft^2\text{-sec-}°R}$ |
| HREF, H (REF) | Reference heat-transfer coefficient based on Fay-Riddell theory, Btu/$ft^2$-sec-°R, see Appendix III |
| $L_S$, $L_T$ | Axial reference length, in. (see Fig. 2) |
| $M_e$ | Mach number at boundary layer edge |
| MACH NO., M | Free-stream Mach number |
| MODEL | Model configuration |
| MU | Free-stream viscosity, lb-sec/$ft^2$ |
| $N_x$,$N_y$,$N_z$ | Direction cosines of the outward unit normal vector at each measurement location on the External Tank and SRB's. See Table 3. |
| OTS | Orbiter, external tank, and both solid rocket boosters |
| P | Free-stream pressure, psia |
| PT | Tunnel stilling chamber pressure, psia |
| Q | Free-stream dynamic pressure, psia |
| QDOT | Heat-transfer rate, Btu/$ft^2$-sec |
| RUN | Data set identification number |
| r | Recovery factor |
| R | Radius or analytical temperature ratio, TR/TT |
| RN | Reference nose radius for HREF and STFR calculations, (RN = Ø.Ø175 FT) |
| RE,RE/FT | Free-stream Reynolds numbers per foot, $ft^{-1}$ |
| RHO | Free-stream density, lbm/$ft^3$ |
| ROLL-SECTOR, $\phi$ | Tunnel sector angle of roll, deg |
| SRB | Solid Rocket Booster |
| STFR | Theoretical stagnation point Stanton number for a Ø.Ø175-ft radius sphere calculated from Fay-Riddell theory |

| | |
|---|---|
| S.F. | Schmidt-Boelter gage scale factor the reciprocal of $C_1$, Btu/ft$^2$-sec/mv |
| T | Temperature, $^oR$<br>Free-stream static temperature, $^oR$ |
| TC-NO | Thin skin thermocouple identification number |
| $T_e$ | Temperature at the edge of the boundary layer, $^oR$ |
| THETA, $\theta$ | Model circumferential measurement coordinate, deg (see Fig. 2) |
| TI | Model initial wall temperature prior to injection in the tunnel, $^oR$ |
| TR | Boundary layer recovery temperature, $^oR$ |
| TT | Free-stream total temperature, $^oR$ |
| TW | Model wall temperature, $^oR$ |
| V | Free-stream velocity, ft/sec |
| X | Model axial coordinate, in. |
| X/L | Nondimensionalized axial location |
| YAW | Model angle of yaw, deg |
| $\delta$ | The included angle between the free stream velocity vector and local unit normal to the model surface, deg |
| $\gamma$ | Ratio of specific heats |
| $\rho$ | Model wall density, lbm/ft$^3$ |

CONFIGURATION - OTS + Tr + TVC

| | |
|---|---|
| *OTS | Ø.Ø175 scale orbiter, External Tank, right and left Solid Rocket Boosters (SRB's) |
| Tr | Transition strips (SRB's and Orbiter) |
| TVC | Thrust Vector Control Pods on left SRB only |

*OTS $B_{62}$ $C_{12}$ $M_{16}$ $W_{116}$ $E_{52}$ $V_8$ $R_{18}$ $F_{10}$ $T_{38}$ $S_{26}$

$B_{62}$ - Fuselage

$C_{12}$ - Canopy

$M_{16}$ - OMS Pod

$W_{116}$ - Wing

$E_{52}$ - Elevon

$V_8$ - Vertical tail

$R_{18}$ - Rudder

$F_{10}$ - Body flap

$T_{38}$ - External Tank (Spike Nose)

$S_{26}$ - Solid Rocket Booster

## 1.0 INTRODUCTION

The work reported herein was performed by the Arnold Engineering Development Center (AEDC), Air Force Systems Command (AFSC), under Program Element 921E02, Control Number 9E02. The program was jointly sponsored by NASA-Marshall Space Flight Center (NASA/MSFC), Huntsville, Alabama and the Aerospace Flight Dynamics Testing Office (DOFA), Arnold Engineering Development Center (AEDC). The NASA/MSFC project manager was Mr. L. D. Foster and the AEDC/DOFA project manager was Mr. J. T. Best. NASA/MSFC representatives supporting the test were Mr. John Warmbrod, REMTECH Corporation and Mr. E. C. Knox, Rockwell International both of Huntsville, Alabama. AEDC representatives were Messrs W. K. Crain and K. W. Nutt, Calspan Field Services, Inc./AEDC Division. The results were obtained by Calspan Field Services, Inc./AEDC Division, operating contractor for the Aerospace Flight Dynamics testing effort at the AEDC, AFSC, Arnold Air Force Station, Tennessee. The tests were performed in the von Karman Gas Dynamics Facility (VKF) Aerothermal Tunnel C during the time period October 21-22, 1982. The AEDC Project Number was C795VC (Calspan Project Number V--C-2E).

Due to the low driving potential (TR-TW < 100 $^{O}$F) experienced in conducting heat transfer tests in Tunnel A, NASA has been concerned about the validity of the interference heating measurements (Hi/Hu) obtained on the External Tank in previous Tunnel A tests (Refs. 1-2). With the advent of the M = 4 Aerothermal Tunnel addition to Tunnel C, came the capability to provide conditions similar to those run in Tunnel A but at a much higher driving potential (TR-TW > 800 $^{O}$F). In addition, conditions could be provided in the Aerothermal Tunnel to duplicate space shuttle flight length Reynolds number.

Objectives of the program were: to obtain interference heating data on the integrated vehicle at conditions comparable to previous tests run in Tunnel A, at similar and higher values of driving potential. Secondly, to obtain External Tank interference heating data at conditions comparable to flights STS 1-4 . The configuration tested was the 0.0175 scale 60-OTS integrated Space Shuttle Vehicle. Test conditions covered the range M = 4.00, Re/ft = 4 x $10^6$, TT = 270 - 980$^{O}$F for the first objective. Model attitude was varied from -5 to +5 degrees angle of attack and -3 to +3 degrees angle of side slip. For the second objective, the model was run at launch attitudes experienced on STS1-4 and conditions of M = 4.00, Re/ft = 0.4 x $10^6$ (STS 1-3) and Re/ft = 6.6 x $10^6$ (STS 4). These data provide a base then, for assessment of the validity of the interference heating factors (Hi/Hu) obtained in Tunnel A, as well as a base for comparisons between Aerothermal Tunnel C, Tunnel A and flight.

A summary of the test data transmitted is shown in Table 1. Inquiries to obtain copies of the test data should be directed to

NASA/MSFC, Huntsville, AL., 35812 or AEDC/DOFA, Arnold AFS, TN, 37389. A microfilm record has been retained in the VKF at AEDC.

# 2.0 APPARATUS

## 2.1 TEST FACILITY

The Mach 4 Aerothermal Tunnel C is a closed-circuit, high temperature, supersonic free-jet wind tunnel with an axisymmetric contoured nozzle and a 25 in.-diam nozzle exit, Fig. 1. This tunnel utilizes parts of the Tunnel C circuit (the electric air heater, the Tunnel C test section and injection system) and operates continuously over a range of pressures from nominally 15 psia at a minimum stagnation temperature of 710°R to 180 psia at a maximum temperature of 1570°R. Using the normal Tunnel C Mach 10 circuit (Series Heater Circuit), the Aerothermal Mach 4 nozzle operates at a maximum pressure and temperature of 100 psia and 1900°R, respectively. The air temperatures and pressures are normally achieved by mixing high temperature air (up to 2250°R) from the primary flow discharged from the electric heater with the bypass air flow (at 1440°R) from the natural gas-fired heater. The primary and the bypass air flows discharge into a mixing chamber just upstream of the Aerothermal Tunnel stilling chamber. The entire Aerothermal nozzle insert (the mixing chamber, throat and nozzle sections) is water cooled by integral, external water jackets. Since the test unit utilizes the Tunnel C model injection system, it allows for the removal of the model from the test section while the free-jet tunnel remains in operation. A description of the Tunnel C equipment may be found in the Test Facilities Handbook, Ref. 3.

## 2.2 TEST ARTICLE

The 60-OTS model is a 0.0175 scale thin skin thermocouple model of the Rockwell International Vehicle 5 Configuration (Fig. 2). The 60-OTS configuration tested was composed of the following Rockwell component buildup: OTS = $B_{62}$ $C_{12}$ $M_{16}$ $W_{116}$ $E_{52}$ $V_8$ $R_{18}$ $F_{10}$ $T_{38}$ $S_{26}$. The model was constructed of 17-4 stainless steel with a nominal skin thickness of 0.030 in. at all instrumented areas except the intertank area. A new instrumented corrugated intertank, Fig. 2b, was installed for this test. Effective skin thickness of this section was 0.040 in. In addition, the external tank was configured with the 30 deg/10 deg spiked nosetip, (Fig. 2b). Thrust Vector Control Pods (TVC) (Fig. 2d) were added to the aft skirt of the left SRB.

An orbiter elevon deflection angle of zero degrees was run throughout the test. The orbiter speed brake and body flap were set at zero degrees deflection also.

Boundary layer trips were used on the orbiter and each SRB to generate a turbulent boundary layer (Fig. 2e). The trips consisted of 0.025 in.-diam balls spaced on 0.075 in. centers.

Trips for the SRBs were attached to formfitted steel rings while trips for the orbiter were attached to a steel strip. Axial location of the trips on the SRBs was X/L =0.033 and for the orbiter the location was X/L = 0.040.

An installation photograph of the 60-OTS model in Tunnel C is shown in Fig. 3a and an installation sketch of the model is shown in Fig. 3b.

2.3 TEST INSTRUMENTATION

The instrumentation, recording devices, and calibration methods used to measure the primary tunnel and test data parameters are listed in Table 2a along with the estimated measurement uncertainties. The range and estimated uncertainties for primary parameters that were calculated from the measured parameters are listed in Table 2b.

The 60-OTS model was instrumented with chromel-constantan thin-skin thermocouples (30 gage wire) and 0.050 in.-diam thermopile Schmidt-Boelter heat transfer gages. Schmidt-Boelter gage instrumentation was placed in locations not instrumented on previous space shuttle tests such as struts, cable trays and other support structure and protuberances. Instrumentation location is listed in Table 3.

The External Tank was instrumented with 164 thin skin thermocouples and 28 Schmidt Boelter gages. Instrumentation was composed of gages and thermocouples carrying the 600, 700, 2000 and 5000 series designation numbers. Instrumentation location is depicted in Fig. 4a for the External Tank and in Figs. 4b-4f for the support hardware; i.e., bipod strut, cable tray, thrust struts, etc.

The SRBs were instrumented as follows: the right SRB (Fig. 5a) contained 8 thin skin thermocouples and 6 Schmidt-Boelter gages. The left hand SRB (Fig. 5b) contained 16 thin skin thermocouples. Right SRB instrumentation was composed of the 3000 series designation numbers while the 4000 series designation pertained to the left SRB. Instrumentation location on associated SRB hardware (support struts, kick rings, etc.) is illustrated in Fig. 5c-5e.

The Schmidt-Boelter gages were provided by Medtherm Corporation of Huntsville, Alabama. The gage is a direct reading heat flux gage with a chromel-constantan thermocouple vapor-deposited on the gage surface. The addition of the thermocouple to the gage allows measurement of surface temperature and heat flux simultaneously. The principle of operation of the gage is based on axial heat conduction from the gage surface to a heat sink embedded within the gage. The difference in temperature between two points along the path of heat flow from the surface to the sink is proportional to the heat transferred and therefore the heat flux absorbed. At two such points, the Medtherm gages have thermocouple junctions which form a differential thermoelectric circuit, providing a self generating EMF between the two output

leads directly proportional to the heat transfer rate. The gages were built in-place and are therefore an integral part of the 6Ø-OTS model. Schmidt-Boelter gage calibrations were performed by the Medtherm Corporation. The resulting calibration constants are presented in Table 4.

# 3.Ø TEST DESCRIPTION

## 3.1 TEST CONDITIONS

A summary of the nominal test conditions is given below:

| M | PT, psia | TT, °R | P, psia | T, °R | $Re/ft \times 10^{-6}$ |
|---|---|---|---|---|---|
| 4.00 | 175 | 1440 | 1.1 | 350 | 3.6 |
| ↓ | 140 | 1240 | 0.9 | 300 | 3.6 |
| ↓ | 120 | 1050 | 0.8 | 250 | 4.0 |
| ↓ | 102 | 980 | 0.7 | 230 | 3.8 |
| ↓ | 60 | 740 | 0.4 | 180 | 3.5 |
| ↓ | 119 | 740 | 0.8 | 180 | 6.6 |
| ↓ | 20 | 1430 | 0.1 | 350 | 0.4 |

Data were obtained on the External Tank and Solid Rocket Boosters over the attitude range -5 to +5 degrees angle of attack and -3 to +3 degrees angle of yaw. Yaw angles were achieved by pitching and rolling the model.

A test summary showing the configuration tested and the variables for each run is presented in Table 5.

## 3.2 TEST PROCEDURES

### 3.2.1 General

In the continuous flow wind tunnels (A, B, C), the model is mounted on a sting support mechanism in an installation tank directly underneath the tunnel test section. The tank is separated from the tunnel by a pair of fairing doors and a safety door. When closed, the fairing doors, except for a slot for the pitch sector, cover the opening to the tank and the safety door seals the tunnel from the tank area. After the model is prepared for a data run, the personnel access door to the installation tank is closed, the tank is vented to the tunnel flow, the safety and fairing doors are opened, and the model is injected into the airsteam. After the data are recorded, the model is retracted into the tank and the sequence is reversed with the tank being vented to atmosphere to allow access to the model in preparation for the next run.

### 3.2.2 Data Acquisition

The initial step prior to recording the test data was to cool the model uniformly to approximately 35°F. This was accomplished by positioning the model in the Tunnel C cooling manifold

and bathing the model in chilled high pressure air. The model was then injected out of the cooling environment into the tunnel flow. Instrumentation outputs were scanned approximately 17 times per second starting upon injection and continuing to approximately 1.5 seconds after the model reached tunnel centerline. The model was then retracted into the tank area below the tunnel and the cooling cycle begun to cool the model to an isothermal state. A photograph of the model in the cooling rig is shown in Fig. 6.

The model data were acquired using a 256 channel analog to digital multiplexing system. These measurements as well as tunnel flow measurements, model attitude measurements and time were processed by the Random Access Data Acquisition System (RADS) PDP-11 minicomputer and recorded on disc memory for transmission to the facility computer (DEC-1Ø) for data reduction.

## 3.3 DATA REDUCTION

### 3.3.1 Tunnel Parameters

Measured stilling chamber pressure and temperature and the calibrated test section Mach number were used to compute the free-stream parameters. The equations for a perfect gas isentropic expansion from stilling chamber to test section were modified to account for real gas effects.

### 3.3.2 Thin Skin Measurements

The reduction of thin skin temperature data to coefficient form normally involves only the calorimeter heat balance for the thin skin as follows:

$$\text{QDOT} = \rho bc(\text{DTW/DT}) \tag{1}$$

$$\text{H(TR)} = \frac{\text{QDOT}}{\text{TR-TW}} = \frac{\rho bc(\text{DTW/DT})}{\text{TR-TW}} \tag{2}$$

Thermal radiation and heat conduction effects on the thin-skin element are neglected in the above relationship and the skin temperature response is assumed to be due to convective heating only. It can be shown that for constant TR, the following relationship is true:

$$\frac{d}{dt} \ln\left[\frac{\text{TR-TI}}{\text{TR-TW}}\right] = \frac{\text{DTW/DT}}{\text{TR-TW}} \tag{3}$$

Substituting Eq. (3) in Eq. (2) and rearranging terms yields:

$$\frac{\text{H(TR)}}{\rho bc} = \frac{d}{dt} \ln\left[\frac{\text{TR-TI}}{\text{TR-TW}}\right] \tag{4}$$

By assuming that the value of $H(TR)/\rho bc$ is a constant it can be seen that the derivative (or slope) must also be constant. Hence, the term

$$\ln\left[\frac{TR-TI}{TR-TW}\right]$$

is linear with time. This linearity assumes the validity of Eq. (2) which applies for convective heating only. The evaluation of conduction effects will be discussed later.

The assumption that H(TR) and c are constant is reasonable for this test although small variations do occur in these parameters. The variations of H(TR) caused by changing wall temperature and by transition movement with wall temperature are trivial for the small wall temperature changes that occur during data reduction. The value of the model material specific heat, c, was computed by the relation

$$c = 0.0797 + (5.556 \times 10^{-5})TW, \quad \text{(17-4 PH Stainless steel)} \qquad (5)$$

The maximum variation of c over the curve fit was less than 1.5 percent. Thus, the assumption of constant c used to derive Equation 4 was reasonable. The value of density used for the 17-4 PH stainless steel skin was $\rho = 490$ lbm/ft$^3$, and the skin thickness, b, for each thermocouple is listed in Table 3.

The right side of Equation 4 was evaluated using a linear least squares curve fit of 7 consecutive data points to determine the slope. The curve fit used for the final data reduction was started at approximately the time the model arrived on tunnel centerline. H(TR) was then calculated for each thermocouple from the resulting slopes and the appropriate values of $\rho bc$;

$$H(TR) = \rho bc \frac{d}{dt} \ln\left[\frac{TR-TI}{TR-TW}\right] \qquad (6)$$

To investigate conduction effects, a second value of H(TR) was calculated one second later than the value under consideration for final tabulated data. A comparison of these two values was used to identify those thermocouples that were significantly influenced by conduction or system noise. In addition, timewise variation of H(TR) was monitored to insure that the final data were reduced during a time period where H(TR) was constant. Those measurements significantly affected were then deleted from the final data. In general, conduction and/or noise effects were found to be negligible.

### 3.3.3 Schmidt-Boelter Measurement

Measurements obtained from the Schmidt-Boelter gages; i.e., gage output, E, and surface thermocouple output, were used to calculate the incident heat flux (QDOT), wall temperature (TW) and heat transfer coefficient in the following manner. The gage output and surface thermocouple were sampled five consecutive times and then averaged. The average values of the gage output E were then related to the incident heat flux (QDOT) through the gage scale factor.

$$QDOT = (S.F.)(E) \tag{7}$$

The scale factor is equal to the reciprocal of the gage calibration constants ($C_1$) listed in Table 4.

$$S.F. = 1/C_1 \tag{8}$$

Using the same averaging procedure, an average value of gage surface thermocouple output was obtained. The average values were then related to the wall temperature (TW) through the use of a fifth degree polynomial curve fit of the NBS (National Bureau of Standards) tables for chromel-constantan thermocouples. The heat transfer coefficient for each average value was calculated from the following equation:

$$H(TR) = \frac{QDOT}{(TR-TW)} \tag{9}$$

Final data reduction of the Schmidt-Boelter gages was taken at the same time as the thin-skin thermocouples; i.e., when the model reached tunnel centerline. Timewise variation of H(TR) versus time for the various Schmidt-Boelter gages was monitored to insure that the final data were reduced during a time period where H(TR) was constant. For cases where either the gage output or surface thermocouple was faulty, that particular measurement was deleted.

### 3.3.4 Recovery Temperature and R Factor

Since the actual value of the recovery temperature (TR) at each measurement location is not known, three assumed values of TR are used to calculate the local heat transfer coefficients. They are TR = TT, Ø.95 TT, and RTT where R is defined by the analytic temperature ratio TR/TT. The analytic method for determining R was developed by Rockwell International. In this method the following relationships were assumed:

$$R = \frac{TR}{TT} \tag{10}$$

and

$$TR = T_e\left(1 + \frac{\gamma-1}{2}\, r\, M_e^{\,2}\right) \tag{11}$$

$$r = 0.898 \text{ for turbulent flow}$$

with r being the recovery factor and the subscript e identifying local properties at the boundary-layer edge. From these relationships, the temperature ratio can be defined as:

$$R = \frac{1 + 0.2\ r\ M_e^{\,2}}{1 + 0.2\ M^2} \tag{12}$$

which is a function of the recovery factor and the local Mach number. The local Mach number can be written

$$M_e = M_e\ (M, \delta) \tag{13}$$

where $\delta$ is the local surface angle of attack.

The local Mach number can be approximated by using tangent cone flow theory, and was used in Eq. (13) to give R as a function of M and $\delta$. Calculations of R were made for several values of M and $\delta$, and the results were curve fit by Rockwell International. The following equation resulted.

$$R(M,\ \delta) = a_1 + a_2 \cdot (\sin\ \delta)^{a_3} \tag{14}$$

where $a_1$, $a_2$, and $a_3$ are constants for a particular Mach number. Turbulent values of $a_1$, $a_2$, and $a_3$ for this test were provided by Rockwell International and are as follows:

| M | $a_1$ | $a_2$ | $a_3$ |
|---|---|---|---|
| 4.00 | 0.922 | $1.0-a_1$ | 1.965 |

The angle $\delta$ is the included angle between the free stream velocity vector and the local normal to the model surface. $\delta$ was computed using the following equation

$$\delta = \sin^{-1}\left\{(N_x \cos\alpha_s - N_y \sin\alpha_s \sin\phi + N_z\ \sin\alpha_s\ \cos\phi)(-1)\right\}$$

where $N_x$, $N_y$ and $N_z$ are the direction cosines for the local unit normal. Values of $N_x$, $N_y$ and $N_z$ for each thin skin thermocouple and Schmidt-Boelter gage are tabulated in Table 3.

For values of $\delta \le 0$, $R = a_1$.

For R values > 1.0, R = 1.00

Values of heat transfer coefficient H(TT), H(0.95TT) and H(RTT) were normalized using the Fay-Riddell stagnation point

heat transfer coefficient H(REF). The calculation of H(REF) was based on a hemispherical nose radius of 0.0175 ft model scale (1.0 ft full scale). Definition of the calculation of H(REF) is given in Appendix III.

## 3.4 UNCERTAINTY OF MEASUREMENTS

In general, instrumentation calibration and data uncertainty estimates were made using methods recognized by the National Bureau of Standards (NBS). Measurement uncertainty is a combination of bias and precision errors defined as:

$$U = \pm(B + t_{95}S)$$

where B is the bias limit, S is the sample standard deviation and $t_{95}$ is the 95th percentile point for the two-tailed Student's "t" distribution (95-percent confidence interval), which for sample sizes greater than 30 is taken equal to 2.

Estimates of the measured data uncertainties for this test are given in Table 2a. The data uncertainties for the measurements are determined from in-place calibrations through the data recording system and data reduction program.

Propagation of the bias and precision errors of measured data through the calculated data was made in accordance with Ref. 4 and the results are given in Table 2b.

## 4.0 DATA PACKAGE PRESENTATION

Convective heat-transfer-rate distributions were obtained on a 0.0175 scale model of the Space Shuttle Integrated Vehicle. The final tabulated and photographic data were transmitted to NASA/MSFC and AEDC/DOFA with this report. Examples of the tabulated data for the thin skin and Schmidt-Boelter gage measurements are presented in Appendix IV. A photographic log correlating roll number and run number is presented in Table 6.

Representative data from the top centerline of the External Tank ( =0 deg) are presened in Fig. 7. The data from the current test are compared with data from previous entries in Tunnel A i.e., IH-72, IH-85, as well as turbulent theory of Ref. 5. The data pertain to the integrated vehicle while the theory was calculated for interference-free tank alone. Agreement with previous data and theory (upstream of interference regions) is considered good for validation of the basic results.

## REFERENCES


1. Nutt, Kenneth W. "Test Results From the NASA/Rockwell International Space Shuttle Integrated Vehicle Test (IH-85) Conducted in the AEDC-VKF Tunnel A," AEDC-TSR-78-V15, June 1978.

2. Crain, William K. and Nutt, Kenneth W. "Space Shuttle Integrated Vehicle Aerodynamic Interference Heating Test (NASA JSC Test 1H-97)." AEDC-TSR-82-V37, December 1982.

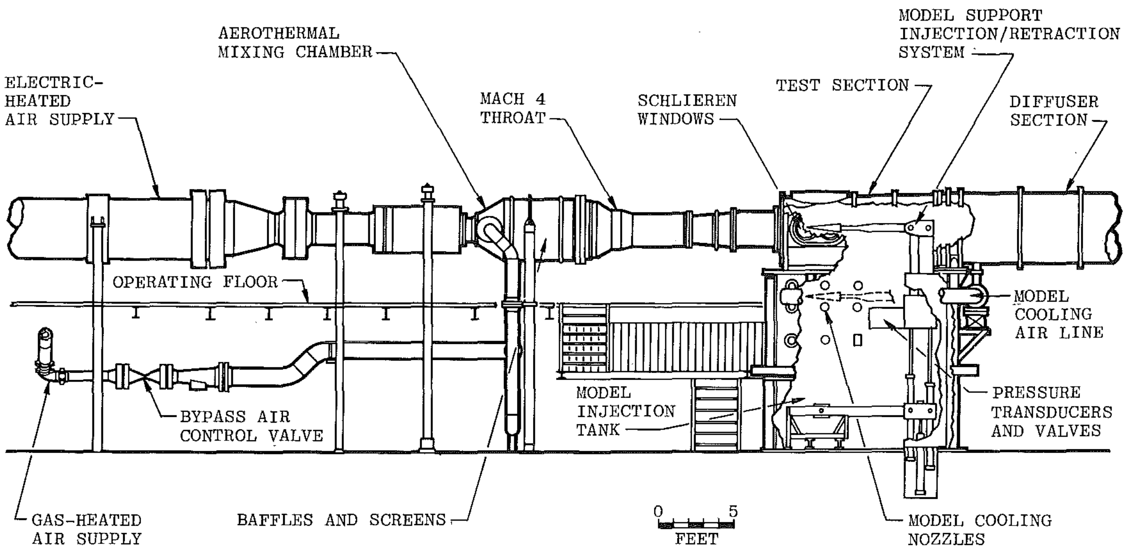
3. Test Facilities Handbook (Eleventh Edition) "von Karman Gas Dynamics Facility," Arnold Engineering Development Center, April 1981.

4. Thompson, J. W., et al. and Abernethy, R. B. "Handbook Uncertainty in Gas Turbine Measurements," AEDC-TR-73-5 (AD755356), February 1973.

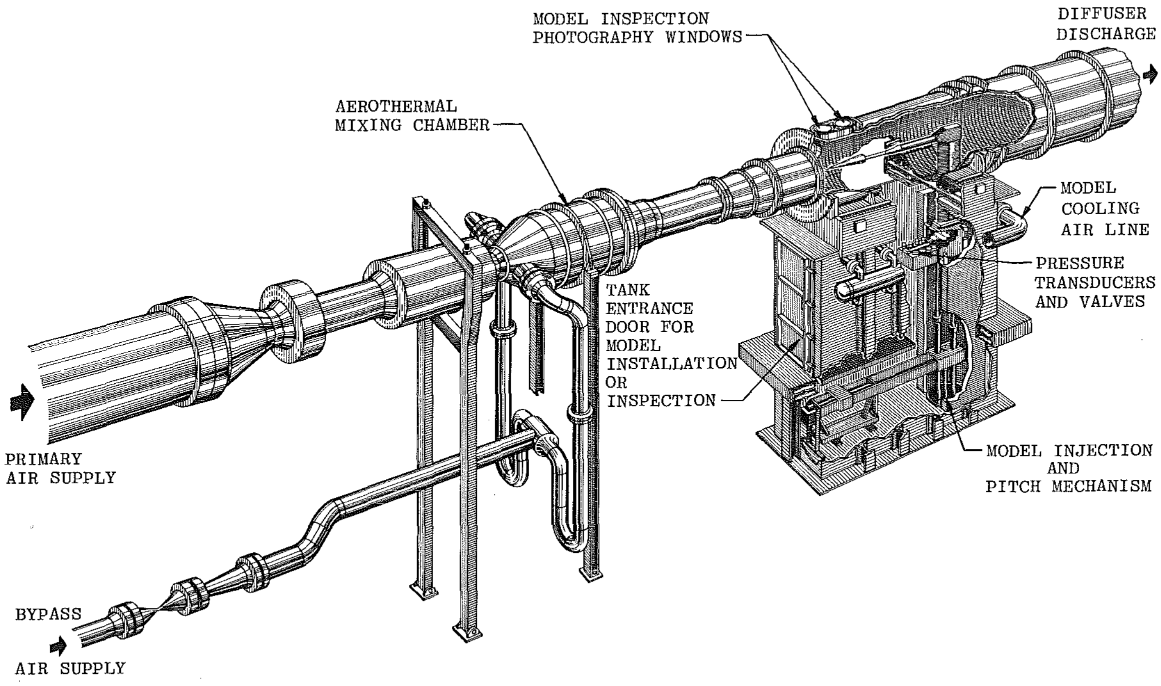
5. DeJarnette, Fred R. "Calculation of Inviscid Surface Streamlines on Shuttle-Type Configurations, Part I - Description of Basic Method." NASA CR-111921, August 1971.

# APPENDIX I

## ILLUSTRATIONS

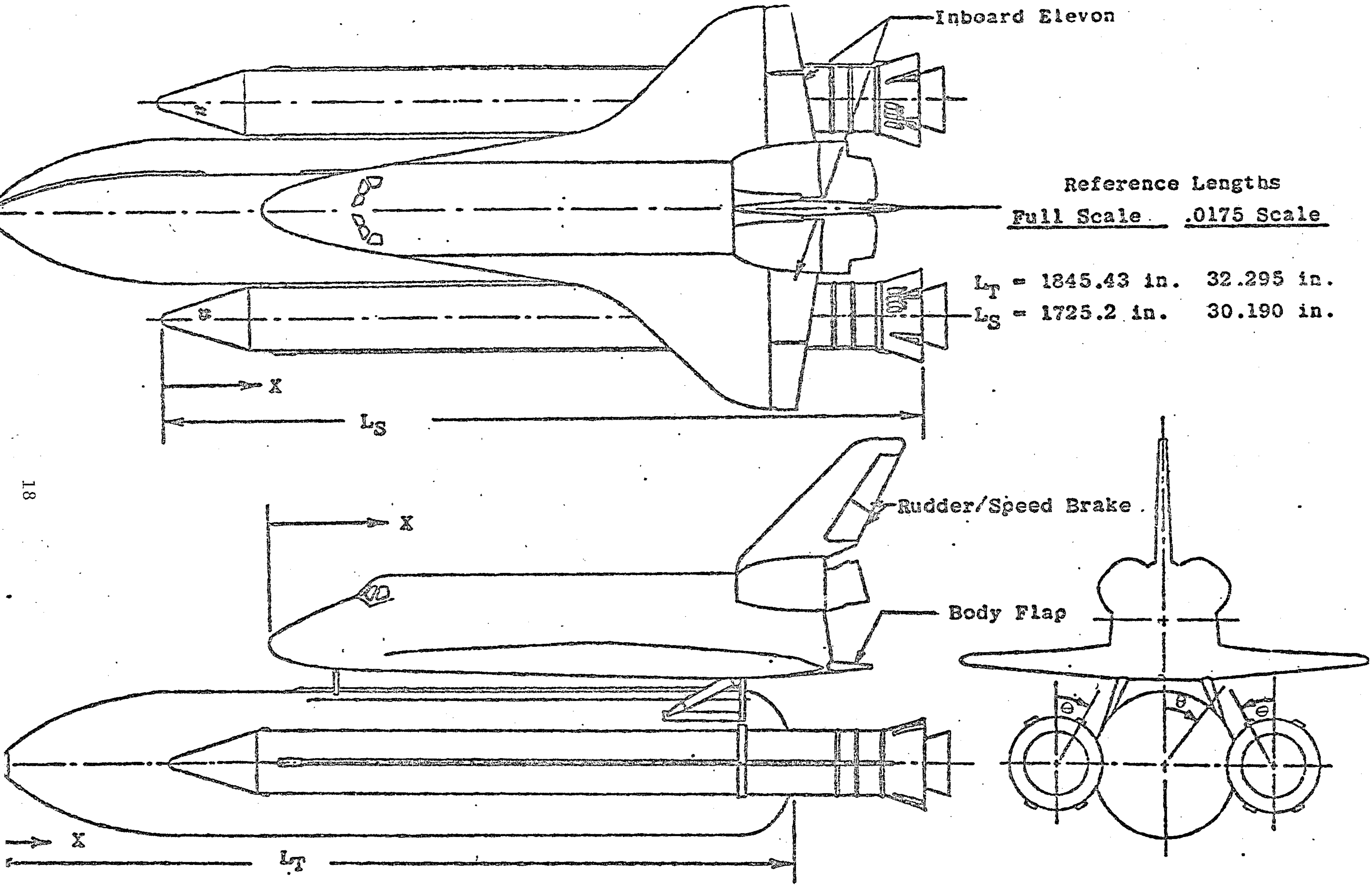



**a. Tunnel assembly**



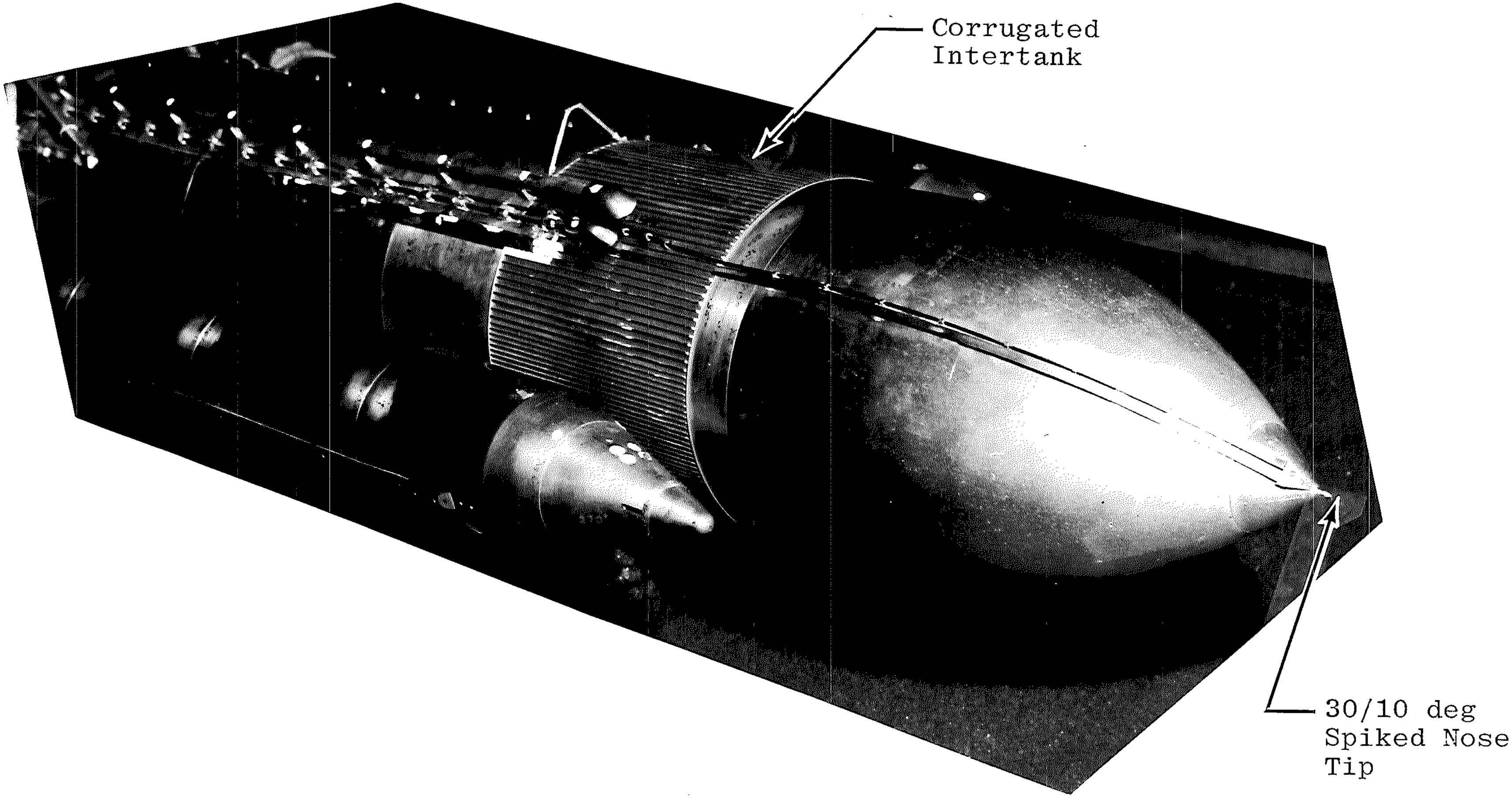

**b. Perspective of tunnel test section area**

**Fig. 1 Tunnel C Mach 4.0 Configuration**

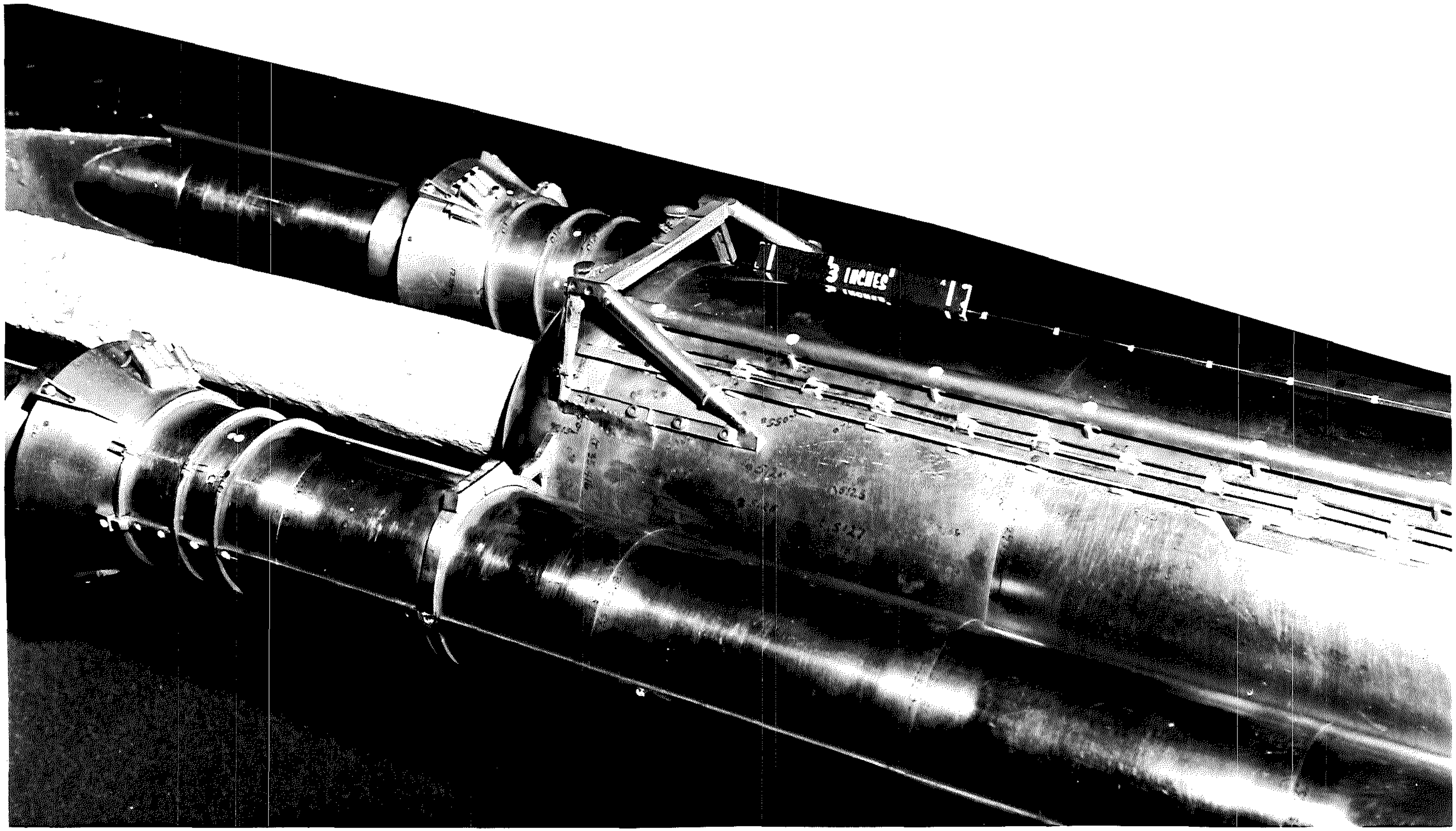



a. Integrated Vehicle - Configuration

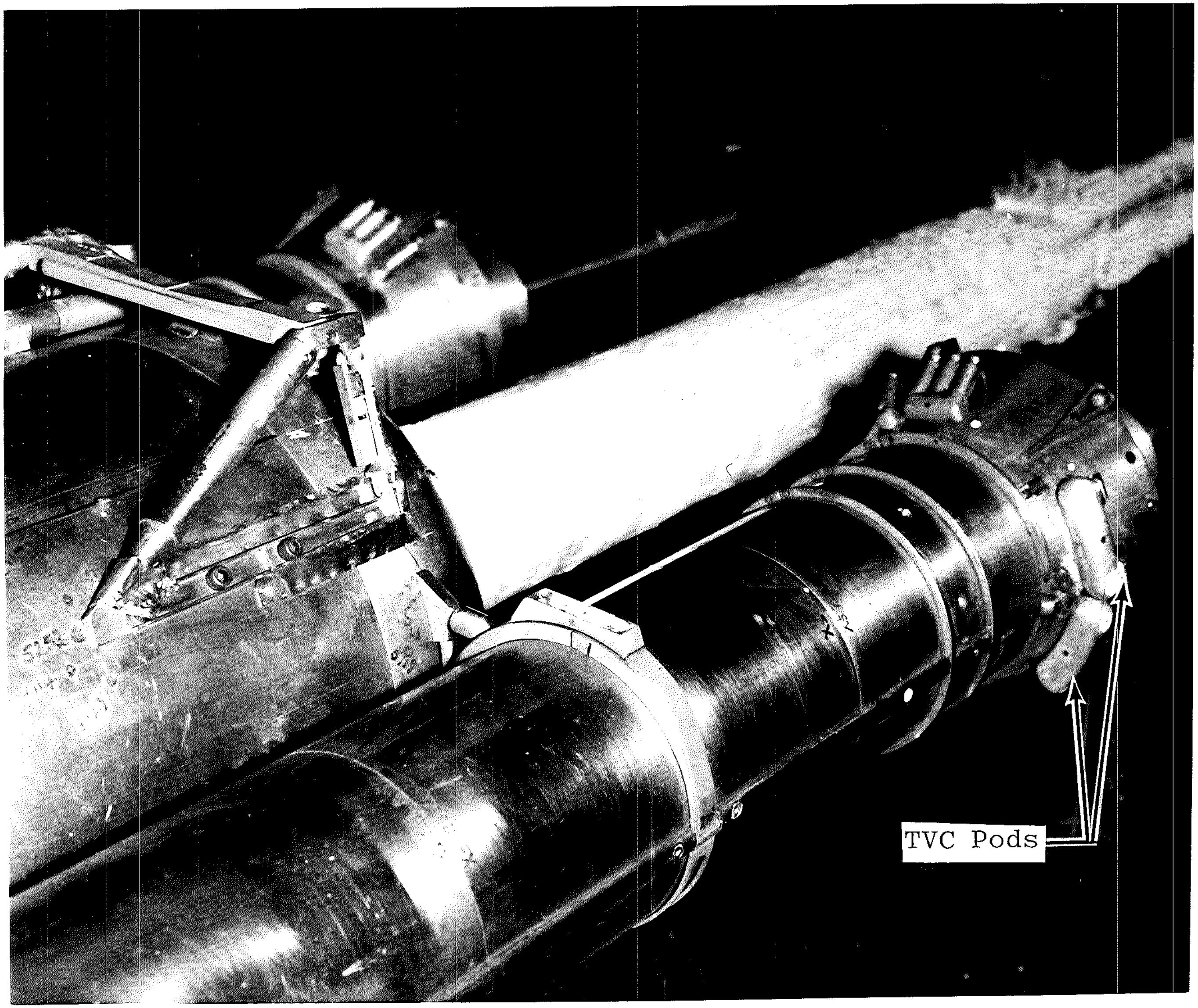
Figure 2. The 60-OTS Integrated Space Shuttle Vehicle



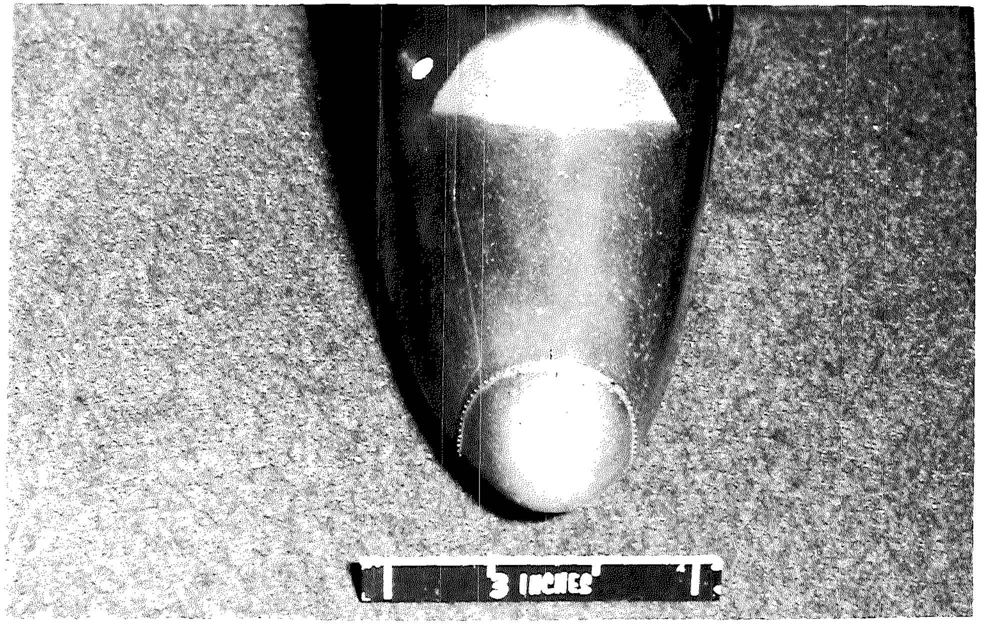

b. External Tank Features (Intertank and Spiked Nose)
Figure 2. Continued



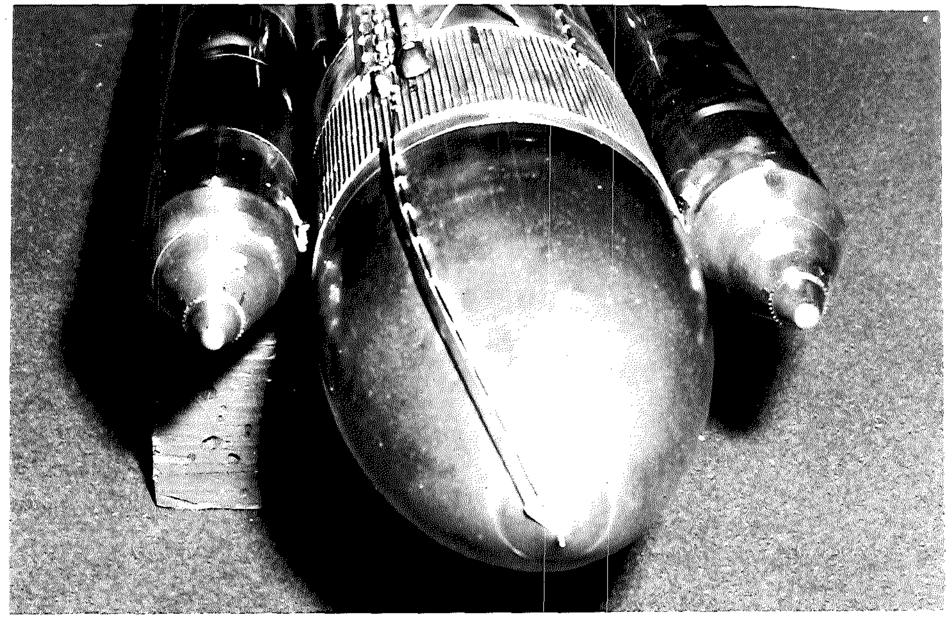
c. Aft Features - External Tank and SRB's
Figure 2. Continued




d. TVC Pods (Left SRB Only)
Figure 2. Continued

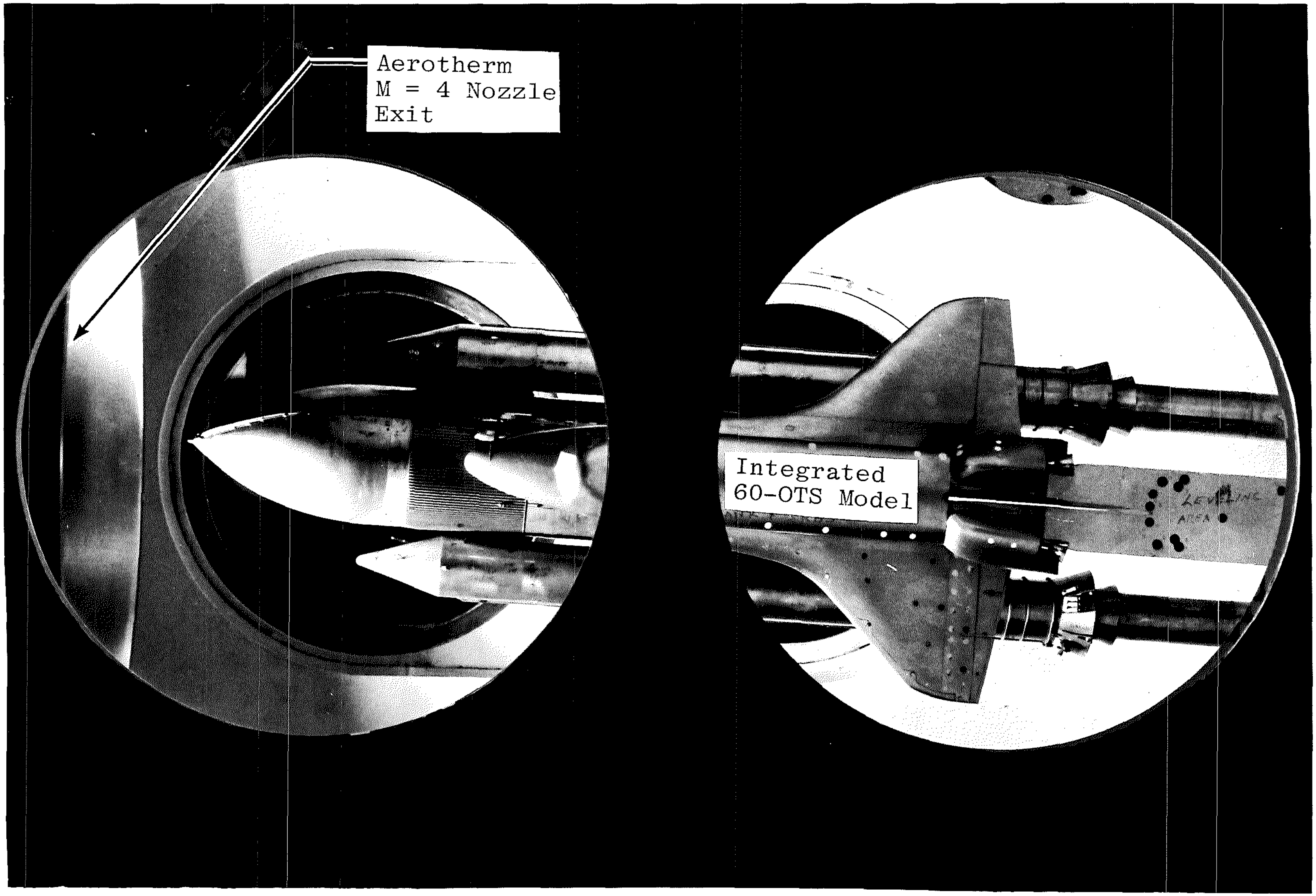



Orbiter
X/L = 0.040

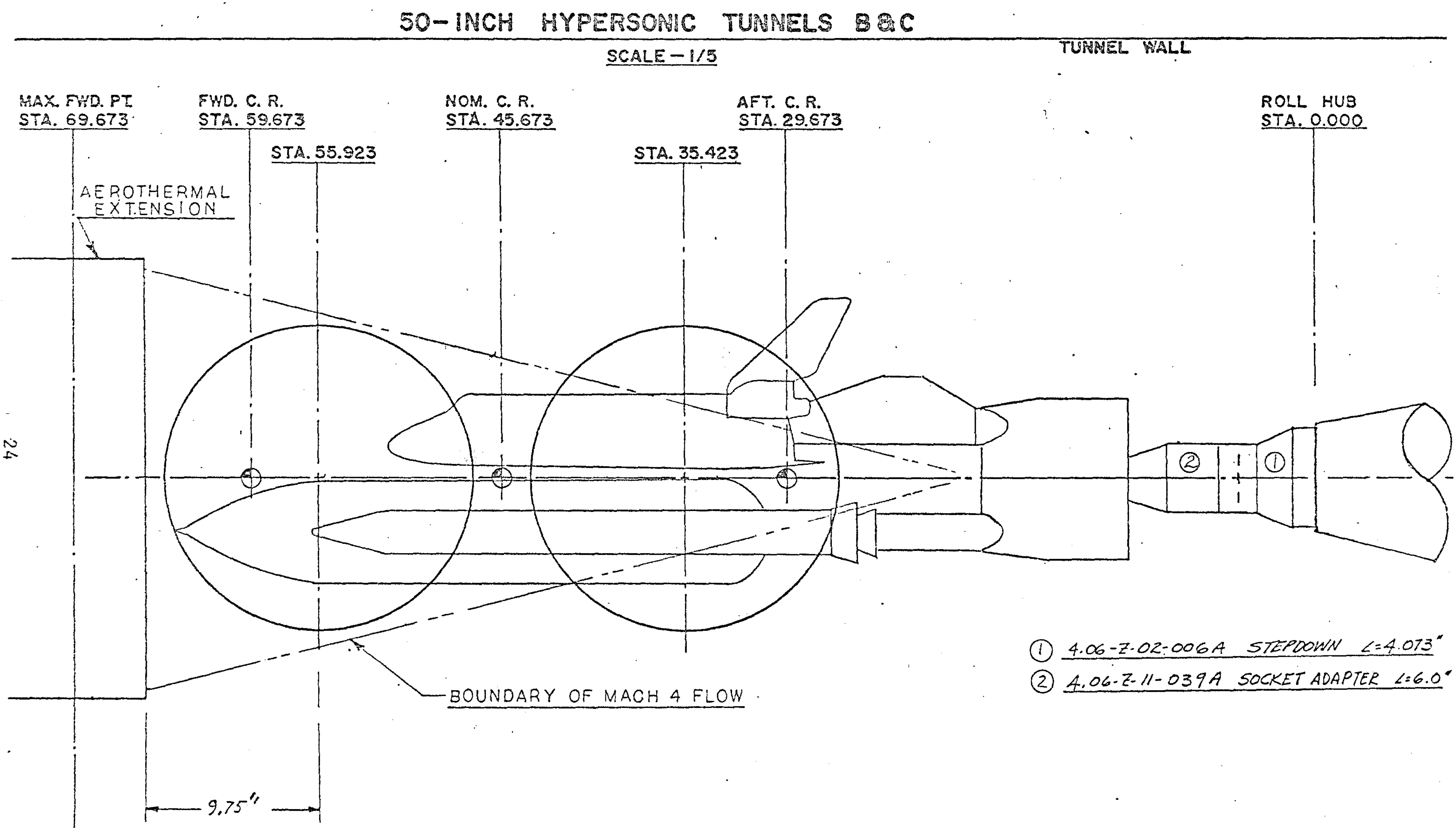


Solid Rocket Boosters
X/L = 0.003

e. Transition Strip Location
Figure 2. Concluded

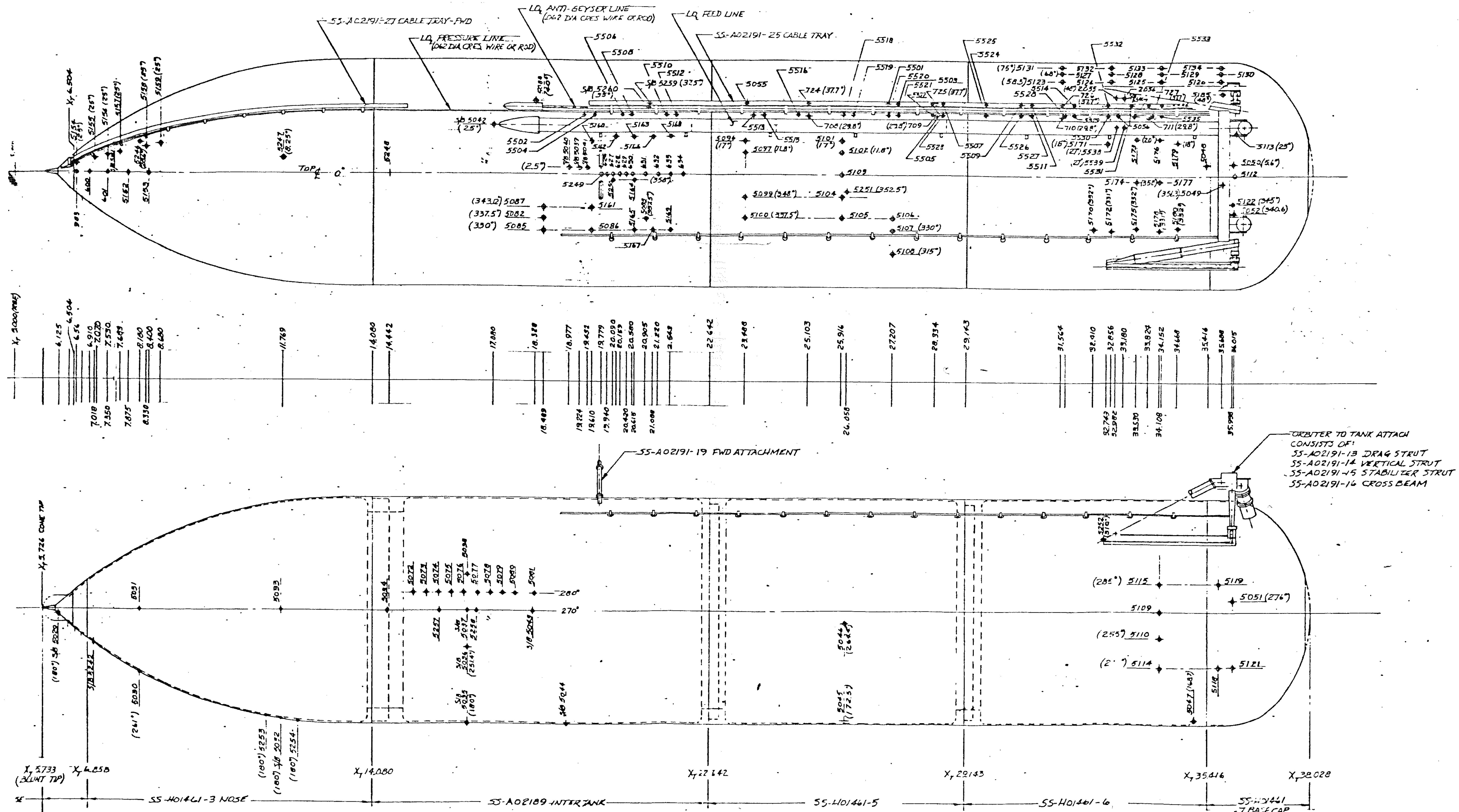



a. Photograph of Installation
Figure 3. Model Installation in Aerotherm Tunnel C



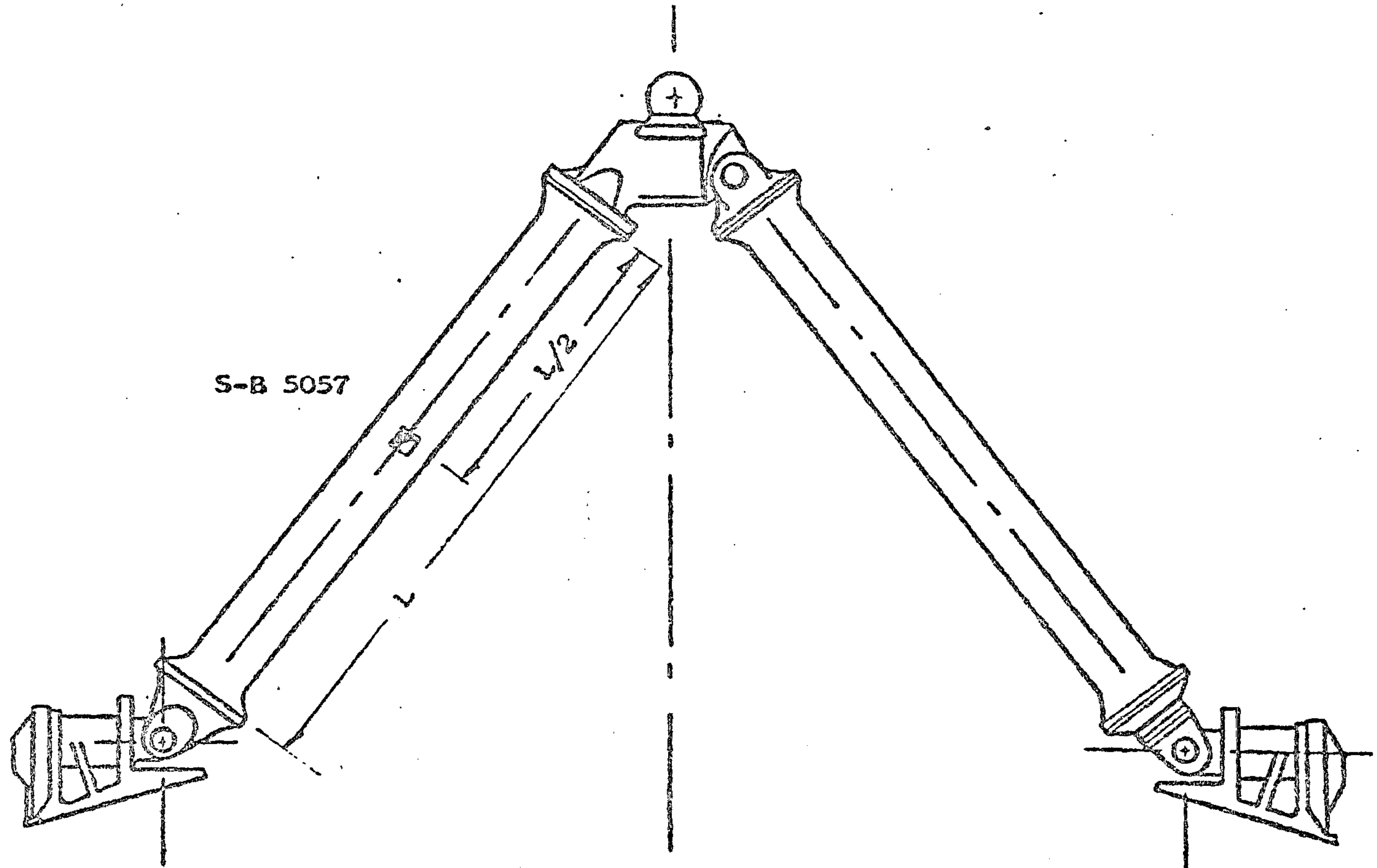

b. Sketch of Installation

Figure 3. Concluded




a. Composite

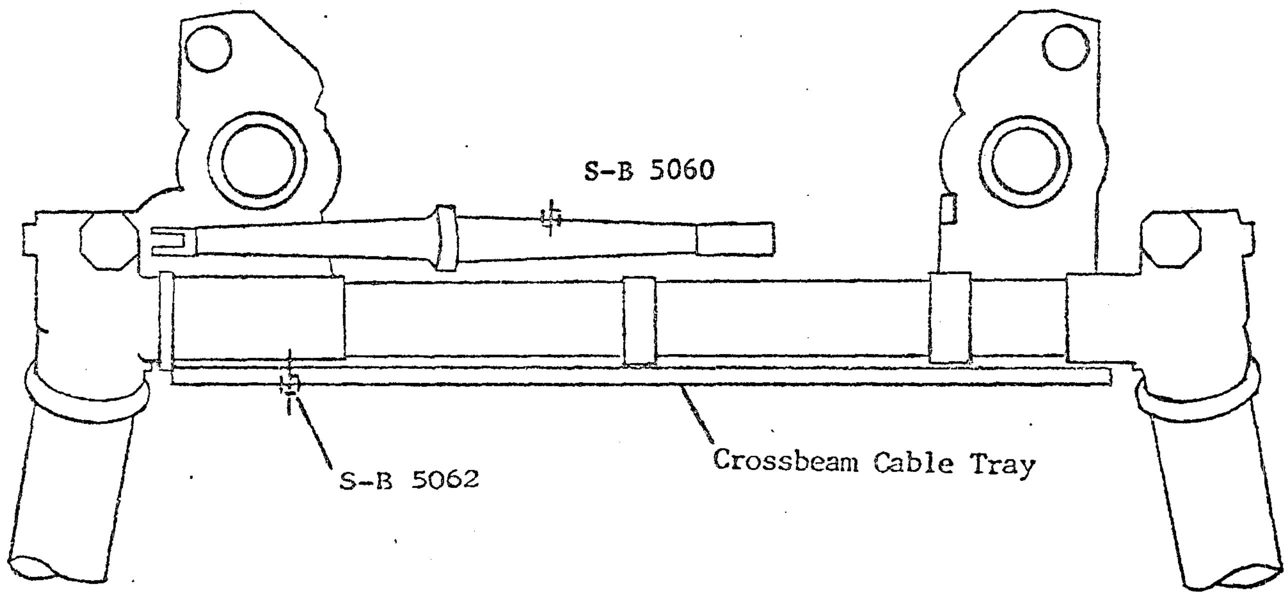
Figure 4. External Tank Instrumentation




View Looking Foward at X 19.773

b. **Foward Orbiter/ET Attach Structure Instrumentation Location**

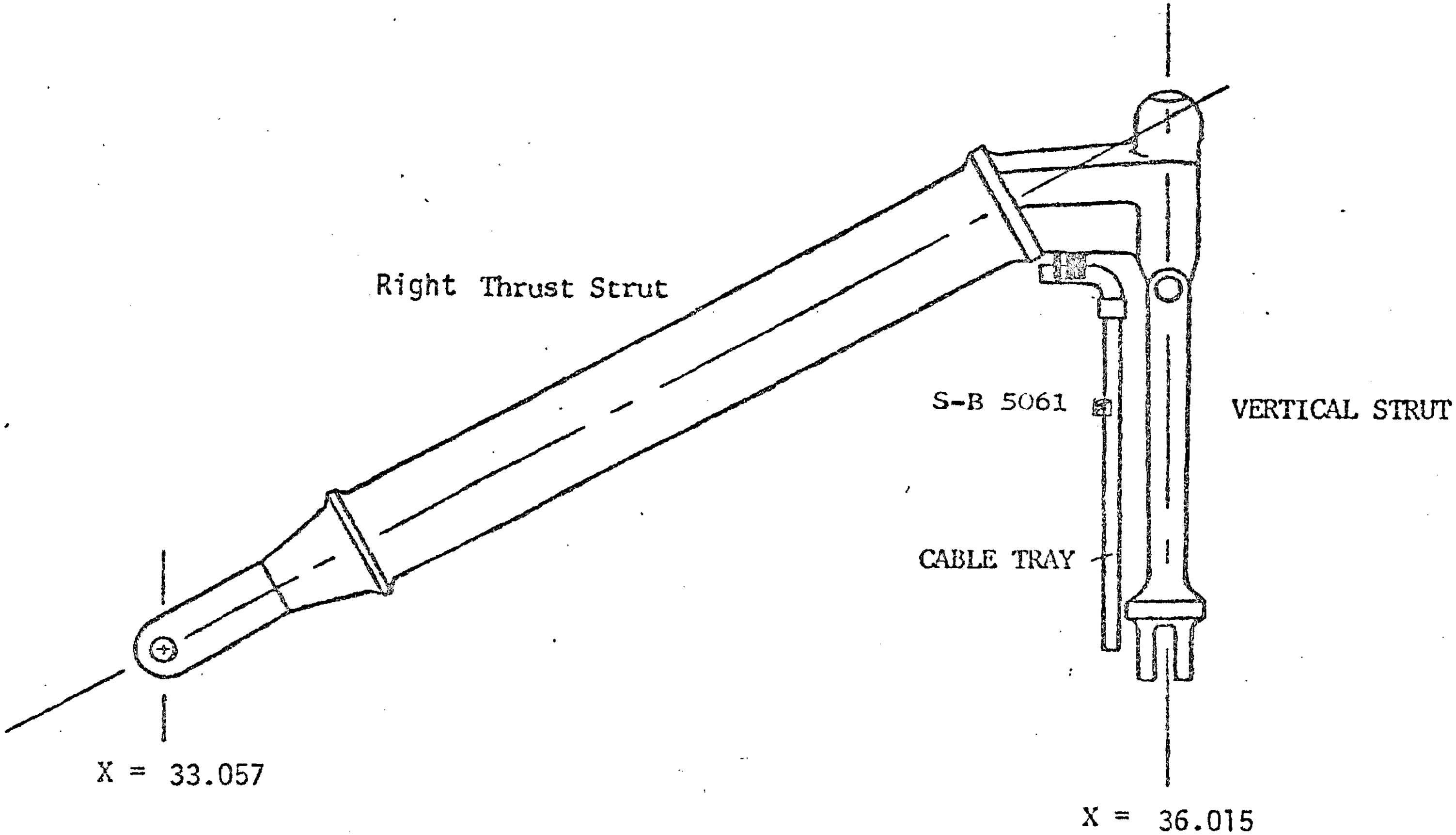
Figure 4. Continued




c. Aft Orb/ET Attach Structure Instrumentation Location

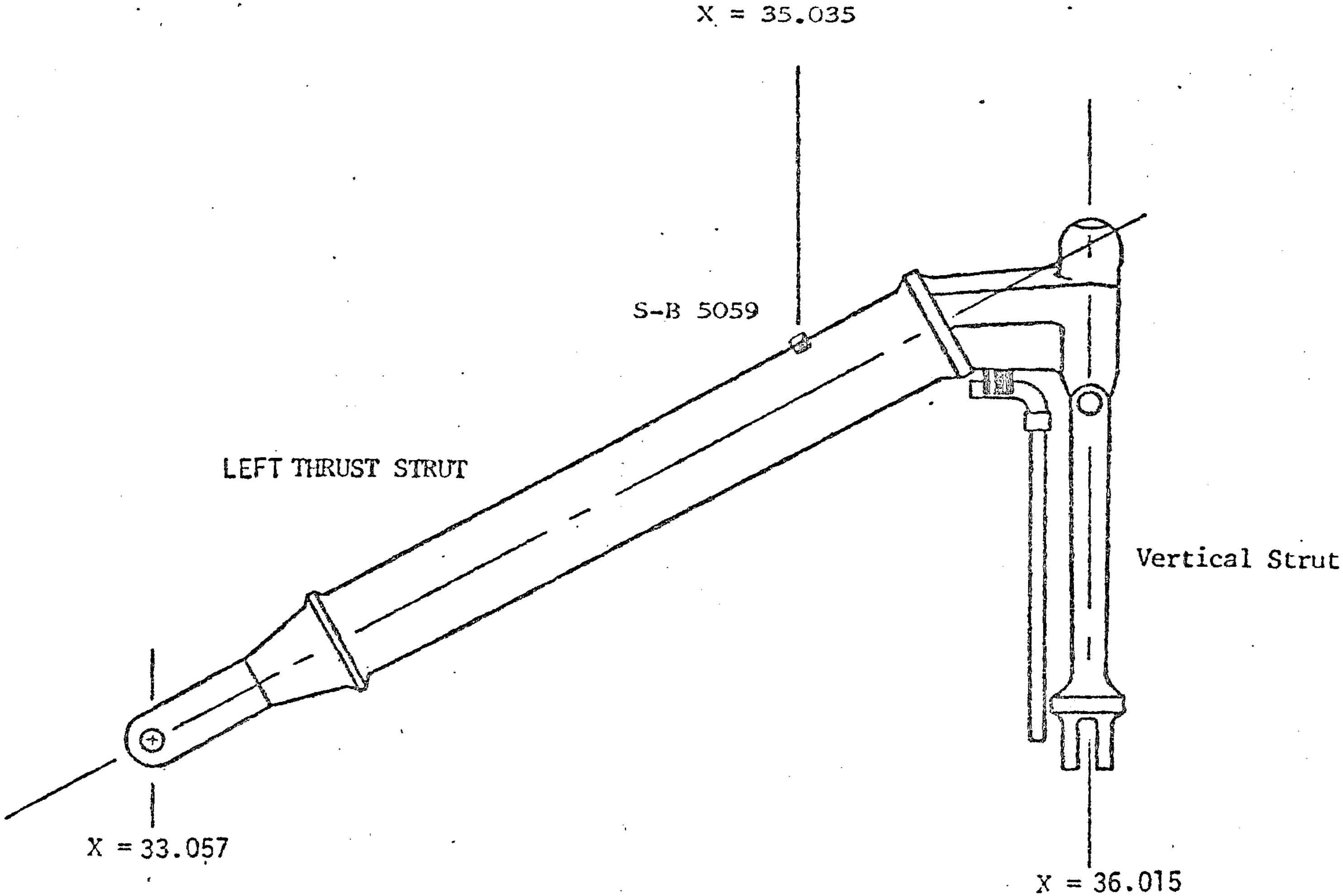
Crossbeam Cable Tray Detail

Figure 4. Continued



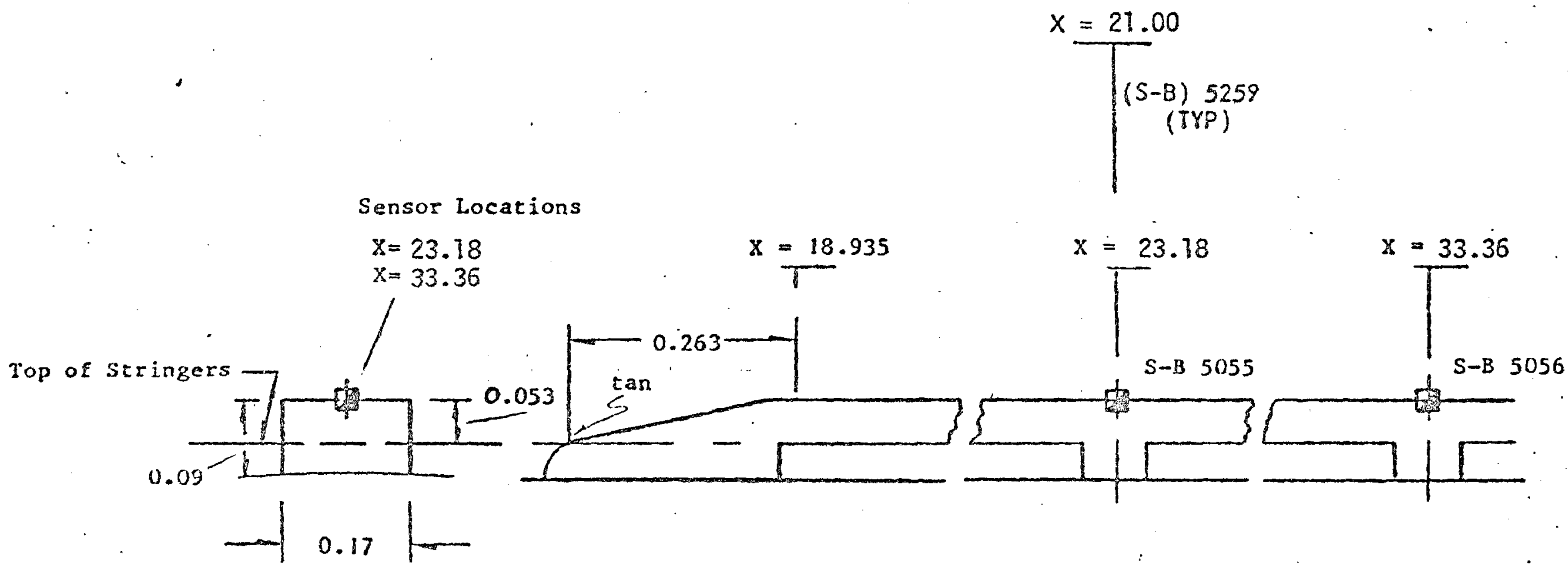

d. Aft Orb/ET Attach Structure Instrumentation Location
Vertical Strut Cable Tray Detail

Figure 4. Continued




e. Aft Orb/ET Attach Structure Instrumentation Location
Thrust Strut Detail

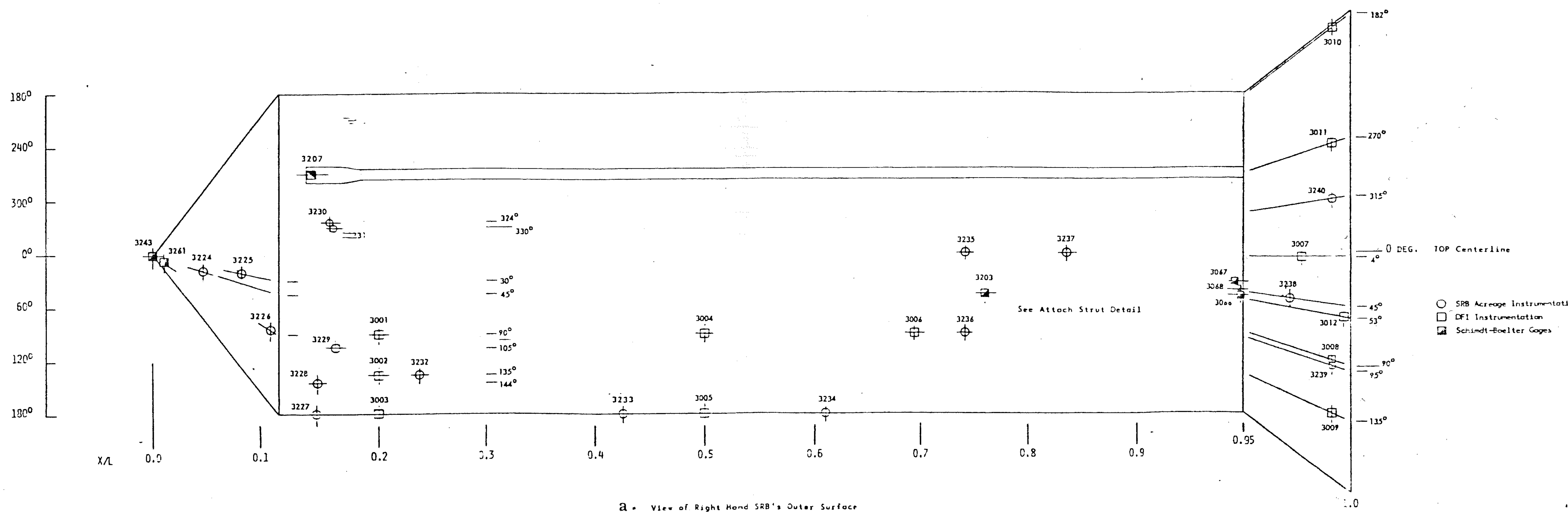
Figure 4. Continued




f. External Tank Protuberance Instrumentation

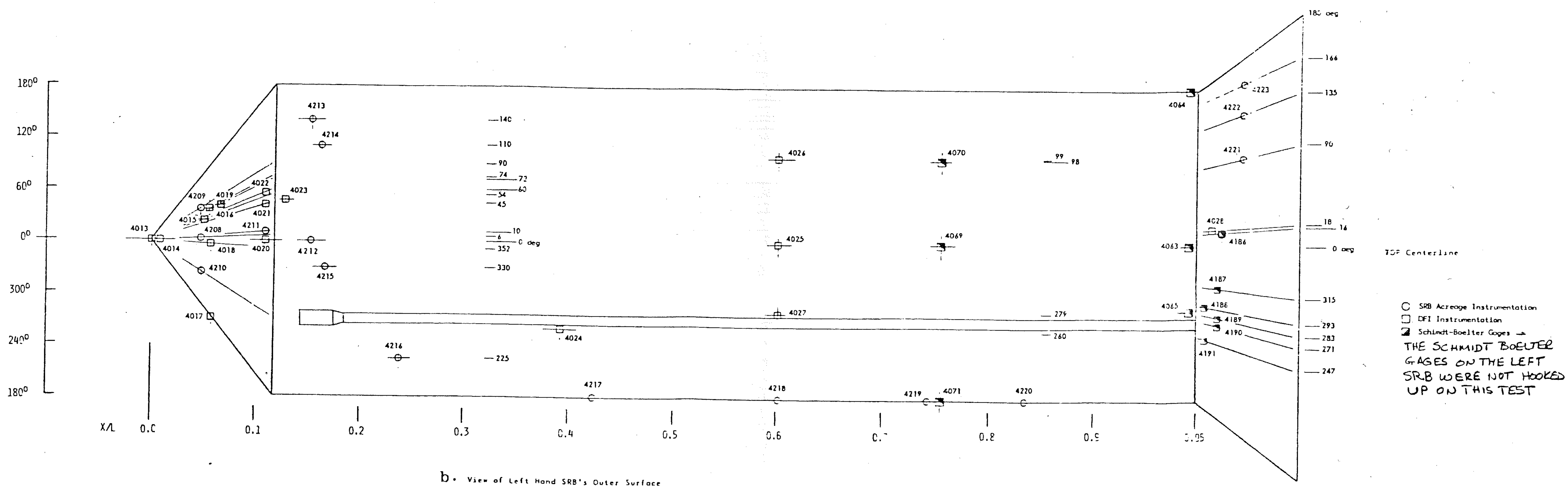
$LH_2$ Cable Tray Detail

Figure 4. Concluded



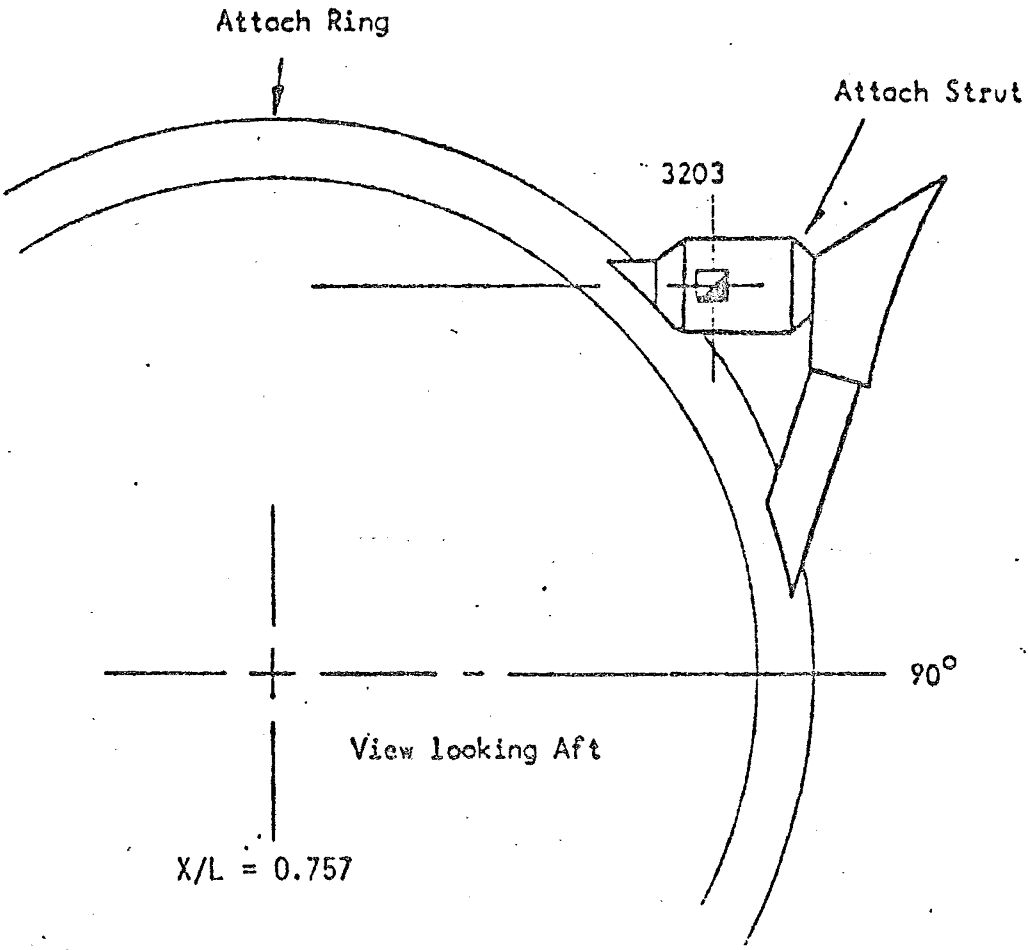
a. View of Right Hand SRB's Outer Surface
(unrolled and split at the bottom ℄)

Figure 5. SRB Instrumentation



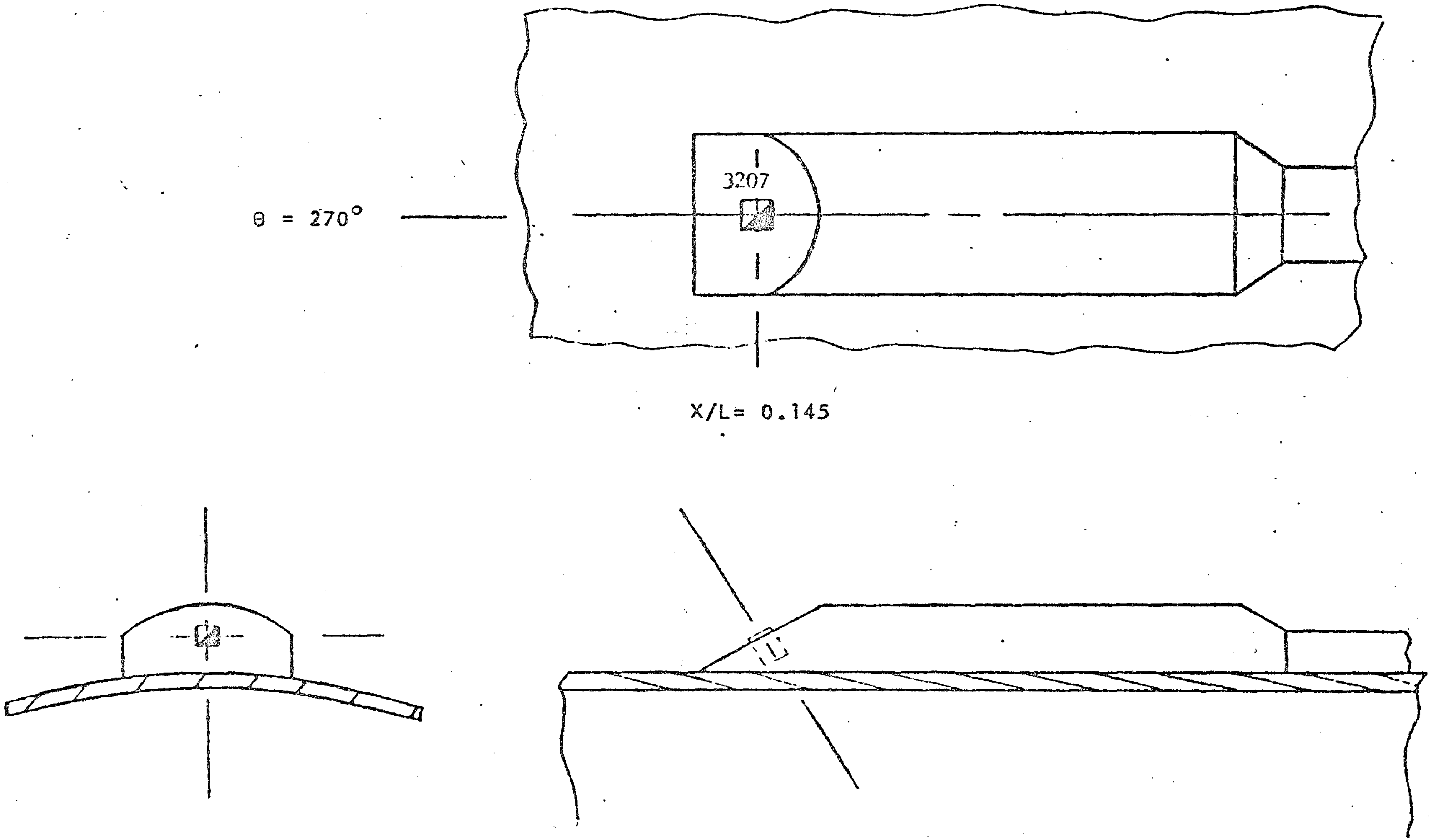

b. View of Left Hand SRB's Outer Surface (unrolled and split at the bottom ℄)

Figure 5. Continued



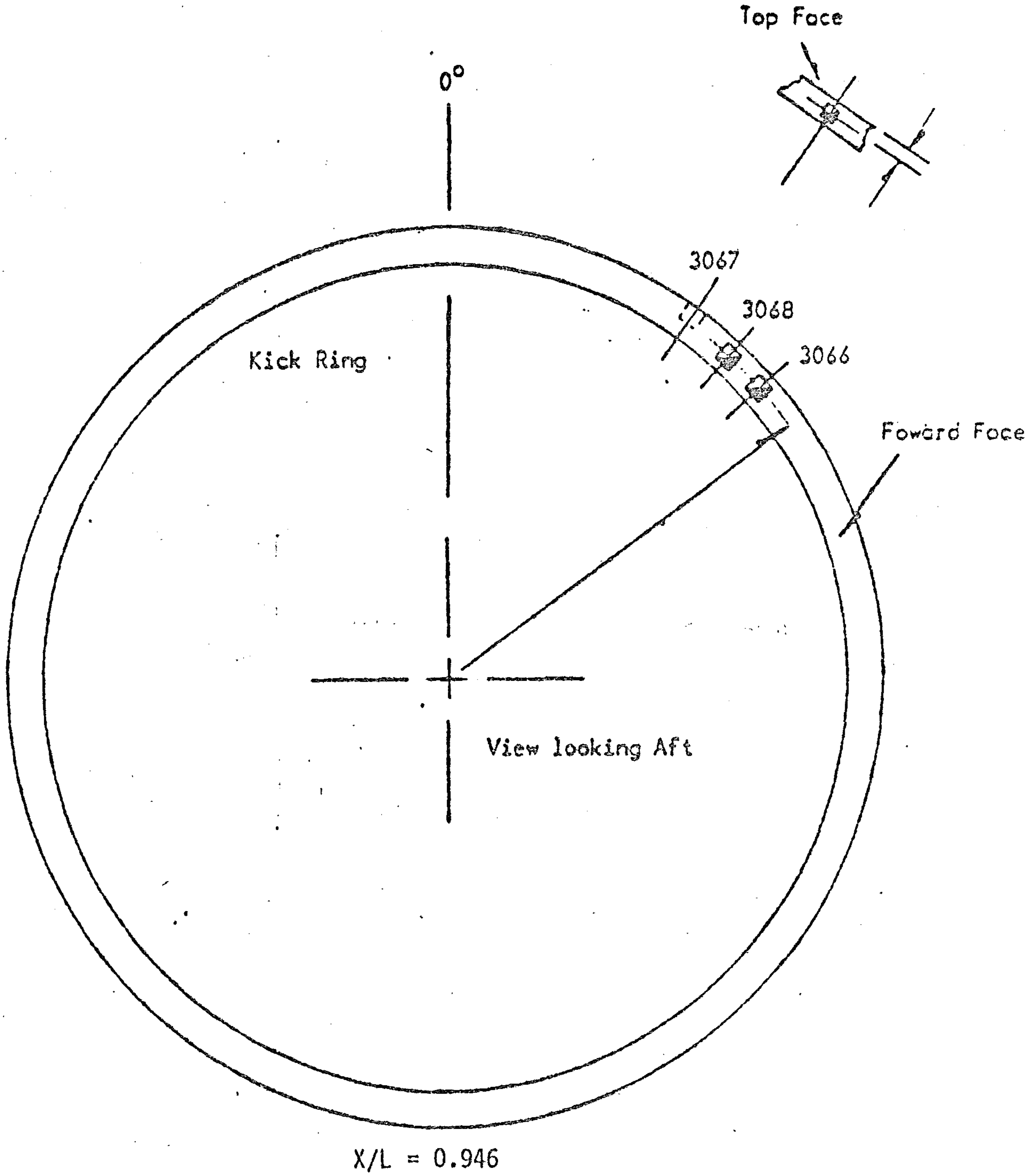

c. Right-Hand SRB Instrumentation Location
SRB/ET Aft Attach Strut Detail

Figure 5. Continued




d. Right-Hand SRB Instrumentation Location
Cable Tray Fairing Detail

Figure 5. Continued




e. Right-Hand SRB Instrumentation Location

Kick Ring Detail

Figure 5. Concluded

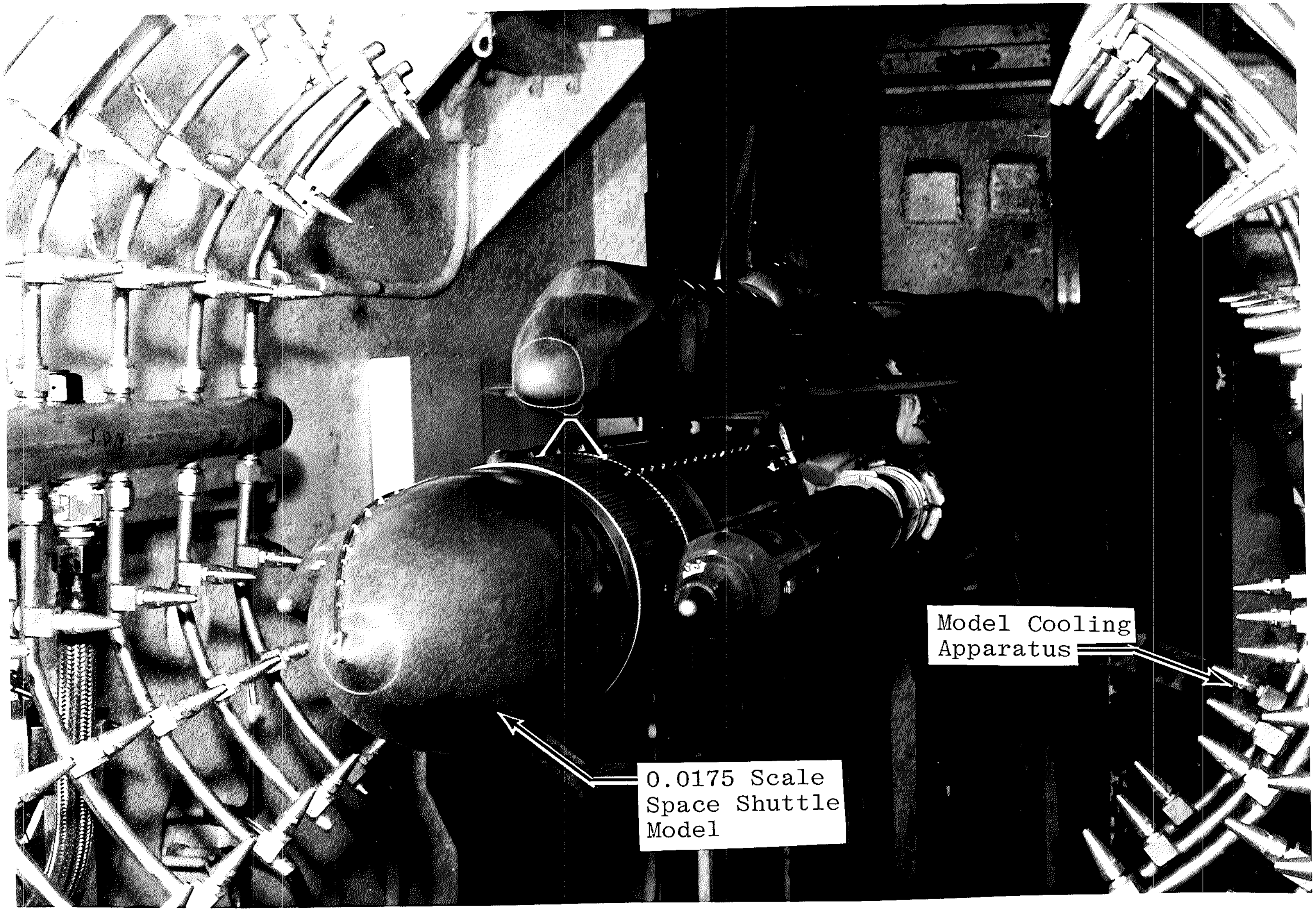



Figure 6. Tunnel C Model Cooling Apparatus

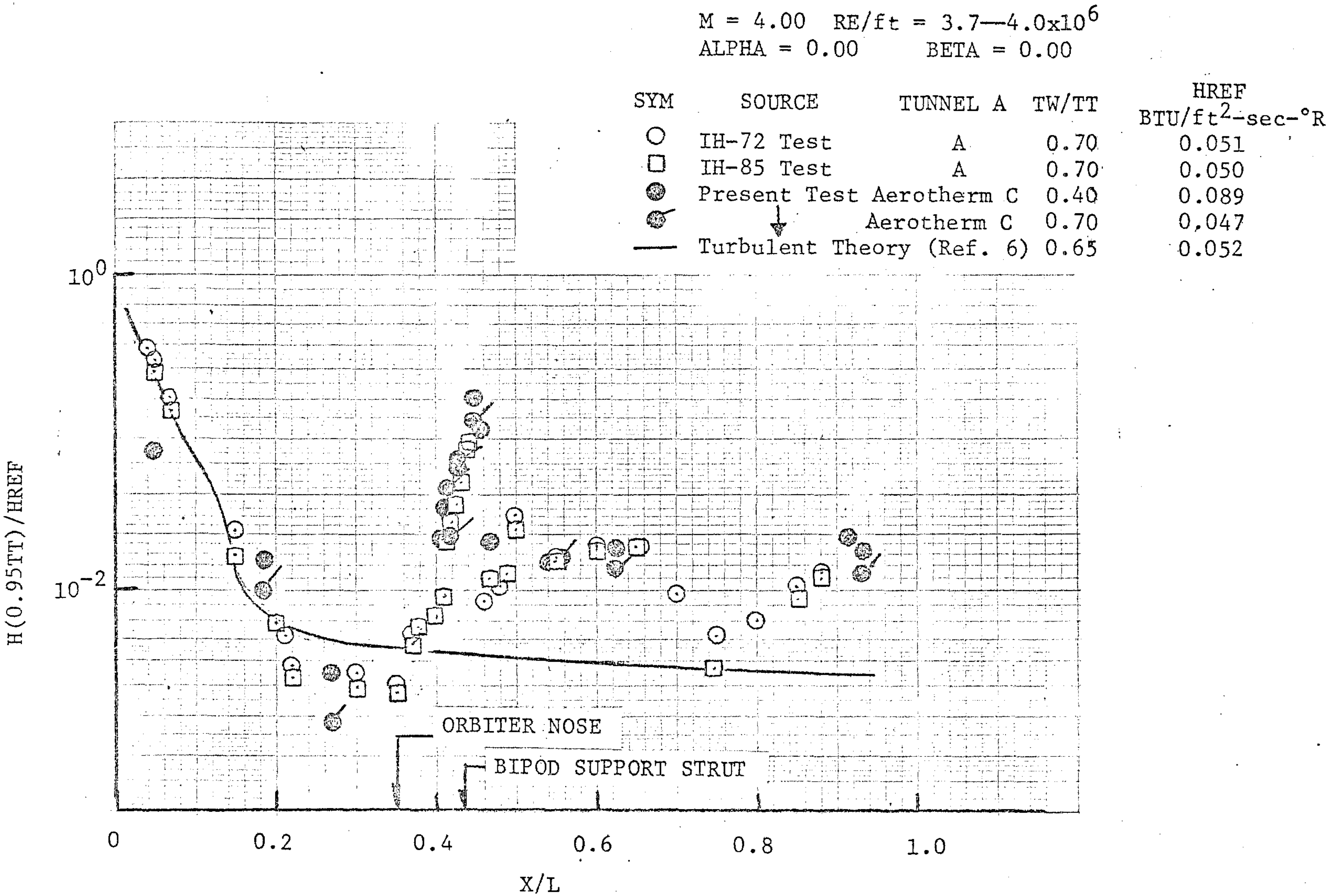



Figure 7. Comparison of External Tank Heating Data from Present Test, IH-85, IH-72 and Theory at M = 4.00

# APPENDIX II

## TABLES

TABLE 1. Data Transmittal Summary

The following items were transmitted to the following:

| | Mr. L. D. Foster<br>NASA/MSFC<br>Huntsville, AL<br>35812 | Mr. J. T. Best<br>AEDC/DOFA<br>MS600<br>Arnold AFS,<br>TN 37389 | Mrs. D. B. Lee<br>NASA/JSC<br>ES3<br>Houston, TX<br>77058 | Mr. Paul Lemoine<br>Rockwell International Space Division<br>12214 Lakewood Blvd.<br>Downey, CA<br>90241 | Mr. E. C. Knox<br>Rockwell International Space Division<br>3322 S. Memorial Pkwy.<br>Huntsville, AL |
|---|---|---|---|---|---|
| Item | No. of Copies | No. of Copies | No. of Copies | No. of Copies | No. of Copies |
| Test Summary Report | 3 | 2 | 1 | 3 | 1 |
| Data Package | 3 | 1 | 1 | 3 | 1 |
| Final Data Tape | 1 | | | 1 | |
| Installation Photos | 1 | 1 | 1 | 1 | 1 |
| Model Photographs | 1 | 1 | | 1 | 1 |
| 70 mm Shadowgraph and Schlieren Stills | | | | | |
| Contact Prints | 1 | 1 | | 1 | |
| Duplicate Negative | 1 | 1 | | | |

| PROJECT NUMBER C795VC<br>TESTING COMPLETED 10/19/82<br>TABLE COMPLETED 12/6/82 | MEASUREMENT UNCERTAINTY<br>TABLE 2.<br>SHEET NO. 1 OF 2 | DATA QUALITY CERTIFIED:<br>ORIGINATOR W. K. Crain DATE 12/6/82<br>CHECKED BY ______ DATE ______ |
|---|---|---|

| Parameter Designation | ESTIMATED MEASUREMENT* Precision Index ±(S) Percent of Reading | Precision Index ±(S) Unit of Measurement | Degree of Freedom | Bias ±(B) Percent of Reading | Bias ±(B) Unit of Measurement | Uncertainty $\pm(B + t_{95}S)$ Percent of Reading | Uncertainty $\pm(B + t_{95}S)$ Unit of Measurement | Range | Type of Measuring Device | Type of Recording Device | Method of System Calibration |
|---|---|---|---|---|---|---|---|---|---|---|---|
| PT, psia | | 0.05 | 30 | | 0.25 | | 0.39 | 0-250 | Setra Systems model 204E variable capacitance pressure transducer | Digital Data Acquisition Analog-to-Digital Converter | In-place application of multiple pressure levels measured with a pressure measuring device calibrated in the Standards Laboratory |
| REFERENCE PRESSURE, psia | | 0.001 | 30 | | 0.009 | | 0.011 | 11-16 | Absolute SETRA Systems model variable capacitance pressure transducer | | |
| TT, °R | | 1 | 30 | | 2 | | 4 | 32-530 | Chromel®-Alumel® Thermocouple | Doric temperature Instrument Digital Multiplexer | Thermocouple verification of NBS conformity/voltage substitution calibration |
| | | 1 | 30 | 0.375 | | (0.375% + 2°R) | | 530-2300 | | | |
| TW, °F (thin skin thermocouples only) | | 1 | 30 | | 2 | | 4 | 0-300 | Chromel®-Constantan® Thermocouple | Thermoplexer/multiverter/RADS/DEC 10 system | Instrument lab calibration against Bureau of Standards |
| TIME, sec | | $5 \times 10^{-4}$ | 30 | Runtime(sec)x5x$10^{-6}$ | | [Runtime(sec)x5x$10^{-6}$] + $10^{-3}$ | | ms-365 days | Systron-Donner time code generator | Digital data acquisition system | |
| SECTOR PITCH ANGLE, deg | | 0.025 | 30 | | | | 0.05 | ±15 | Potentiometer | Digital data acquisition system, analog-to-digital converter | Heidenhain rotary encoder ROD 700 Resolution: 0.0006° Overall Accuracy: 0.001° |
| SECTOR ROLL ANGLE, deg | | 0.15 | 30 | | | | 0.3 | ±180 | | | |

NOTES:

1. Uncertainty for the thin skin measurements in the External Tank corrugated intertank area is undetermined. Due to the geometry of this area only "effective" skin thicknesses were supplied.
2. Use of the Schmidt Boelter gages is a relatively new and unproven technique, especially in the small diameter protuberance areas. Consequently uncertainty on the Schmidt Boelter gage measurements is not quoted.

*REFERENCE: Thompson, J. W. and Abernethy, R. B. et al. "Handbook Uncertainty in Gas Turbine Measurements." AEDC-TR-73-5, February 1973

NOTES:

b. Calculated Parameters

| Parameter Designation | STEADY-STATE ESTIMATED MEASUREMENT* Precision Index (S) Percent of Reading | Precision Index (S) Unit of Measure-ment | Degree of Freedom | Bias (B) Percent of Reading | Bias (B) Unit of Measure-ment | Uncertainty $\pm(B + t_{95}S)$ Percent of Reading | Uncertainty $\pm(B + t_{95}S)$ Unit of Measure-ment | |
|---|---|---|---|---|---|---|---|---|
| | | | | | | | | M |
| M | 0.38 | | >30 | | | 0.76 | | 3.9-4.0 |
| | | | | | | | | PT TT |
| RE/ft,1/ft | 0.9 | | >30 | | | 2.6 | | 60-120 730 |
| | 0.8 | | | | | 2.2 | | 100-180 1000-1440 |
| | 1.1 | | | | | 2.7 | | 20 1440 |
| | | | | | | | | H |
| H(TT),H(0.95TT),H(RTT) (for thin skin thermo-couples only - see Notes 1 and 2 on pg. 1 of this table) | 2 | | >30 | 6 | | 10 | | $1x10^{-2}$ |
| | | | | | | | | $1x10^{-3}$ |
| | 4 | | >30 | 6 | | 14 | | $1x10^{-4}$ |
| | - | | >30 | - | | - | | $<1x10^{-4}$ |

*Abernethy, R. B. et al. and Thompson, J. W. "Handbook Uncertainty in Gas Turbine Measurements." AEDC-TR-73-5 (AD 755356), February 1973.

GC-120-1 (Supersedes VB-16A) 9/81

TABLE 3. Instrumentation and Constants

| Gage, TC No. | Skin Thickness (in.) | X/L | θ (deg) | $N_X$ | $N_Y$ | $N_Z$ |
|---|---|---|---|---|---|---|
| 3001 | 0.0295 | 0.1990 | 90.0000 | 0.0000 | -1.0000 | 0.0000 |
| 3002 | 0.0300 | 0.1990 | 135.0000 | 0.0000 | -0.7070 | -0.7070 |
| 3003 | 0.0300 | 0.1990 | 180.0000 | 0.0000 | 0.0000 | -1.0000 |
| 3004 | 0.0290 | 0.4980 | 90.0000 | 0.0000 | -1.0000 | 0.0000 |
| 3005 | 0.0290 | 0.4980 | 180.0000 | 0.0000 | 0.0000 | -1.0000 |
| 4013 | 0.0285 | 0.0000 | 0.0000 | -1.0000 | 0.0000 | -1.0000 |
| 4014 | 0.0285 | 0.0081 | 0.0000 | -0.3090 | 0.0000 | 0.9510 |
| 4015 | 0.0290 | 0.0497 | 54.0000 | -0.3090 | 0.7690 | 0.5590 |
| 4016 | 0.0290 | 0.0503 | 74.0000 | -0.3090 | 0.9140 | 0.2621 |
| 4017 | 0.0295 | 0.0578 | 180.0000 | -0.3090 | 0.0000 | -0.9511 |
| 4018 | 0.0290 | 0.0578 | 352.0000 | -0.3090 | -0.1324 | 0.9418 |
| 4019 | 0.0295 | 0.0656 | 72.0000 | -0.3090 | 0.9045 | 0.2939 |
| 4020 | 0.0290 | 0.1086 | 0.0000 | -0.3090 | 0.0000 | 0.9511 |
| 4021 | 0.0310 | 0.1086 | 45.0000 | -0.3090 | 0.6725 | 0.6725 |
| 4023 | 0.0315 | 0.1265 | 46.0000 | 0.0000 | 0.7193 | 0.6947 |
| 4024 | 0.0300 | 0.3906 | 260.0000 | 0.0000 | -0.9850 | -0.1736 |
| 4026 | 0.0295 | 0.5990 | 99.0000 | 0.0000 | 0.9877 | -0.1564 |
| 4027 | 0.0300 | 0.5990 | 279.0000 | 0.0000 | -0.9877 | 0.1564 |
| 3224 | 0.0324 | 0.0462 | 45.0000 | -0.3090 | -0.6725 | 0.6725 |
| 3226 | 0.0290 | 0.1086 | 90.0000 | -0.3090 | 0.9511 | 0.0000 |
| 4208 | 0.0300 | 0.0462 | 6.0000 | -0.3090 | 0.0994 | 0.9458 |
| 4209 | 0.0290 | 0.0462 | 90.0000 | -0.3090 | -0.9511 | 0.0000 |
| 4210 | 0.0290 | 0.0462 | 270.0000 | -0.3090 | -0.9511 | 0.0000 |
| 5030 | 0.0315 | 0.0760 | 174.0000 | -0.4790 | 0.0920 | -0.8730 |
| 5031 | 0.0324 | 0.0760 | 264.0000 | -0.4790 | -0.8730 | -0.0920 |
| 5033 | 0.0325 | 0.1871 | 270.0000 | -0.1440 | -0.9900 | 0.0000 |
| 5034 | 0.0320 | 0.2700 | 270.0000 | 0.0000 | -1.0000 | 0.0000 |
| 5246 | 0.0314 | 0.0760 | 25.0000 | -0.4790 | 0.4200 | 0.7710 |
| 5247 | 0.0324 | 0.1871 | 8.2500 | -0.1440 | 0.1420 | 0.9790 |
| 5248 | 0.0290 | 0.2700 | 0.0000 | 0.0000 | 0.0000 | 1.0000 |
| 5046 | 0.0305 | 0.6295 | 264.4000 | 0.0000 | -0.9950 | -0.0980 |
| 5047 | 0.0325 | 0.9078 | 168.8000 | 0.0000 | 0.1940 | -0.9810 |
| 5048 | 0.0323 | 0.9156 | 5.6000 | 0.0000 | 0.0980 | 0.9950 |
| 5049 | 0.0300 | 0.9275 | 356.3000 | 0.0000 | -0.0650 | 0.9980 |
| 5050 | 0.0300 | 0.9373 | 5.6000 | 0.0000 | 0.0980 | 0.9950 |
| 5051 | 0.0300 | 0.9373 | 276.0000 | 0.0000 | -0.9950 | 0.1050 |
| 5052 | 0.0305 | 0.9373 | 340.6000 | 0.0000 | -0.3320 | 0.9430 |
| 5249 | 0.0300 | 0.4350 | 0.0000 | 0.0000 | 0.0000 | 1.0000 |
| 5250 | 0.0300 | 0.4440 | 358.0000 | 0.0000 | -0.0350 | 0.9990 |
| 5251 | 0.0310 | 0.6300 | 352.5000 | 0.0000 | -0.1310 | 0.9910 |
| 5252 | 0.0327 | 0.8370 | 310.0000 | 0.0000 | -0.7660 | 0.6430 |
| 5156 | 0.0331 | 0.0507 | 25.0000 | -0.5550 | 0.3520 | 0.7540 |
| 699 | 0.0326 | 0.0500 | 29.8000 | -0.5570 | 0.4130 | 0.7210 |
| 715 | 0.0326 | 0.0500 | 37.7000 | -0.5570 | 0.5080 | 0.6570 |
| 5158 | 0.0328 | 0.0805 | 25.0000 | -0.4650 | 0.3740 | 0.8020 |
| 5159 | 0.0328 | 0.0913 | 25.0000 | -0.4320 | 0.3810 | 0.8170 |
| 5160 | 0.0400 | 0.4800 | 17.0000 | 0.0000 | 0.2920 | 0.9560 |
| 5162 | 0.0319 | 0.4470 | 20.0000 | 0.0000 | 0.3420 | 0.9400 |
| 5173 | 0.0337 | 0.8610 | 20.0000 | 0.0000 | 0.3420 | 0.9400 |
| 5072 | 0.0400 | 0.2900 | 280.0000 | 0.0000 | -0.9850 | 0.1740 |
| 5073 | 0.0400 | 0.3000 | 280.0000 | 0.0000 | -0.9850 | 0.1740 |
| 5074 | 0.0400 | 0.3100 | 280.0000 | 0.0000 | -0.9850 | 0.1740 |
| 5075 | 0.0400 | 0.3200 | 280.0000 | 0.0000 | -0.9850 | 0.1740 |
| 5076 | 0.0400 | 0.3300 | 280.0000 | 0.0000 | -0.9850 | 0.1740 |
| 5077 | 0.0400 | 0.3400 | 280.0000 | 0.0000 | -0.9850 | 0.1740 |
| 5078 | 0.0400 | 0.3500 | 280.0000 | 0.0000 | -0.9850 | 0.1740 |
| 5079 | 0.0400 | 0.3600 | 280.0000 | 0.0000 | -0.9850 | 0.1740 |

TABLE 3. Continued

| | | | | | | |
|---|---|---|---|---|---|---|
| 5080 | 0.0400 | 0.3700 | 280.0000 | 0.0000 | -0.9850 | 0.1740 |
| 5081 | 0.0400 | 0.3850 | 280.0000 | 0.0000 | -0.9850 | 0.1740 |
| 5082 | 0.0400 | 0.3950 | 337.5000 | 0.0000 | -0.3830 | 0.9240 |
| 5083 | 0.0305 | 0.4700 | 337.5000 | 0.0000 | -0.3830 | 0.9240 |
| 5084 | 0.0305 | 0.5000 | 337.5000 | 0.0000 | -0.3830 | 0.9240 |
| 5085 | 0.0400 | 0.3950 | 330.0000 | 0.0000 | -0.5000 | 0.8660 |
| 5086 | 0.0400 | 0.4310 | 330.0000 | 0.0000 | -0.5000 | 0.8660 |
| 5087 | 0.0400 | 0.3950 | 343.1200 | 0.0000 | -0.2900 | 0.9570 |
| 5088 | 0.0400 | 0.3900 | 40.0000 | 0.0000 | 0.6430 | 0.7660 |
| 5096 | 0.0300 | 0.5500 | 17.0000 | 0.0000 | 0.2920 | 0.9560 |
| 5097 | 0.0300 | 0.5500 | 11.8000 | 0.0000 | 0.3390 | 0.9410 |
| 035 | 0.0295 | 0.5500 | 0.0000 | 0.0000 | 0.0000 | 1.0000 |
| 5099 | 0.0295 | 0.5500 | 348.0000 | 0.0000 | -0.2080 | 0.9780 |
| 5100 | 0.0295 | 0.5500 | 337.5000 | 0.0000 | -0.3830 | 0.9240 |
| 5101 | 0.0320 | 0.6250 | 17.0000 | 0.0000 | 0.2920 | 0.9560 |
| 5102 | 0.0320 | 0.6250 | 11.8000 | 0.0000 | 0.2040 | 0.9790 |
| 5103 | 0.0320 | 0.6250 | 0.0000 | 0.0000 | 0.0000 | 1.0000 |
| 5104 | 0.0310 | 0.6250 | 348.0000 | 0.0000 | -0.2080 | 0.9780 |
| 5105 | 0.0305 | 0.6250 | 337.5000 | 0.0000 | -0.3830 | 0.9240 |
| 5106 | 0.0300 | 0.6650 | 337.5000 | 0.0000 | -0.3830 | 0.9240 |
| 5107 | 0.0300 | 0.6650 | 330.0000 | 0.0000 | -0.5000 | 0.8660 |
| 5108 | 0.0290 | 0.6650 | 315.0000 | 0.0000 | -0.7070 | 0.7070 |
| 5109 | 0.0329 | 0.8800 | 270.0000 | 0.0000 | -1.0000 | 0.0000 |
| 5110 | 0.0329 | 0.8800 | 255.0000 | 0.0000 | -0.9660 | -0.2590 |
| 5111 | 0.0310 | 0.9380 | 315.0000 | 0.0000 | -0.7070 | 0.7070 |
| 5112 | 0.0285 | 0.9380 | 0.0000 | 0.0000 | 0.0000 | 1.0000 |
| 5113 | 0.0305 | 0.9380 | 23.0000 | 0.0000 | 0.3910 | 0.9210 |
| 5114 | 0.0329 | 0.8800 | 240.0000 | 0.0000 | -0.8660 | -0.5000 |
| 5115 | 0.0330 | 0.8800 | 285.0000 | 0.0000 | -0.9660 | 0.2590 |
| 5118 | 0.0305 | 0.9260 | 240.0000 | 0.0000 | -0.8660 | -0.5000 |
| 5119 | 0.0310 | 0.9260 | 285.0000 | 0.0000 | -0.9660 | 0.2590 |
| 5120 | 0.0285 | 0.9380 | 15.0000 | 0.0000 | 0.2590 | 0.9660 |
| 5157 | 0.0300 | 0.0604 | 25.0000 | -0.5260 | 0.3600 | 0.7710 |
| 5121 | 0.0305 | 0.9380 | 240.0000 | 0.0000 | -0.8660 | -0.5000 |
| 5122 | 0.0305 | 0.9380 | 345.0000 | 0.0000 | -0.2590 | 0.9660 |
| 5123 | 0.0335 | 0.8000 | 58.5000 | 0.0000 | 0.8530 | 0.5220 |
| 5124 | 0.0337 | 0.8400 | 58.5000 | 0.0000 | 0.8530 | 0.5220 |
| 5126 | 0.0290 | 0.9260 | 58.5000 | 0.0000 | 0.8530 | 0.5220 |
| 5127 | 0.0340 | 0.8000 | 68.0000 | 0.0000 | 0.9270 | 0.3750 |
| 5128 | 0.0340 | 0.8400 | 68.0000 | 0.0000 | 0.9270 | 0.3750 |
| 5129 | 0.0339 | 0.8800 | 68.0000 | 0.0000 | 0.9270 | 0.3750 |
| 5130 | 0.0300 | 0.9260 | 68.0000 | 0.0000 | 0.9270 | 0.3750 |
| 5131 | 0.0339 | 0.8000 | 75.0000 | 0.0000 | 0.9660 | 0.2590 |
| 5132 | 0.0340 | 0.8400 | 75.0000 | 0.0000 | 0.9660 | 0.2590 |
| 5133 | 0.0338 | 0.8800 | 75.0000 | 0.0000 | 0.9660 | 0.2590 |
| 5134 | 0.0280 | 0.9260 | 75.0000 | 0.0000 | 0.9660 | 0.2590 |
| 2072 | 0.0400 | 0.4200 | 36.3200 | 0.0000 | 0.5920 | 0.8060 |
| 5502 | 0.0400 | 0.4200 | 32.0000 | 0.0000 | 0.5300 | 0.8480 |
| 2073 | 0.0400 | 0.4250 | 36.3200 | 0.0000 | 0.5920 | 0.8060 |
| 5504 | 0.0400 | 0.4300 | 32.0000 | 0.0000 | 0.5300 | 0.8480 |
| 2074 | 0.0400 | 0.4300 | 36.3200 | 0.0000 | 0.5920 | 0.8480 |
| 5506 | 0.0310 | 0.4510 | 32.0000 | 0.0000 | 0.5300 | 0.8480 |
| 5508 | 0.0305 | 0.4590 | 32.0000 | 0.0000 | 0.5300 | 0.8480 |
| 5510 | 0.0305 | 0.4860 | 32.0000 | 0.0000 | 0.5300 | 0.8480 |
| 5512 | 0.0310 | 0.4940 | 32.0000 | 0.0000 | 0.5300 | 0.8480 |
| 5513 | 0.0330 | 0.5560 | 32.0000 | 0.0000 | 0.5300 | 0.8480 |
| 5515 | 0.0315 | 0.5640 | 32.0000 | 0.0000 | 0.5300 | 0.8480 |
| 5516 | 0.0315 | 0.5910 | 32.0000 | 0.0000 | 0.5300 | 0.8480 |

| | | | | | | |
|---|---|---|---|---|---|---|
| 2085 | 0.0335 | 0.6000 | 33.7500 | 0.0000 | 0.5560 | 0.8310 |
| 5518 | 0.0305 | 0.6260 | 32.0000 | 0.0000 | 0.5300 | 0.8480 |
| 5519 | 0.0330 | 0.6340 | 32.0000 | 0.0000 | 0.5300 | 0.8480 |
| 5501 | 0.0325 | 0.6610 | 38.0000 | 0.0000 | 0.6160 | 0.7880 |
| 5520 | 0.0330 | 0.6610 | 32.0000 | 0.0000 | 0.5300 | 0.8480 |
| 5503 | 0.0325 | 0.6690 | 38.0000 | 0.0000 | 0.6160 | 0.7880 |
| 5521 | 0.0330 | 0.6690 | 32.0000 | 0.0000 | 0.5300 | 0.8480 |
| 5505 | 0.0320 | 0.6960 | 38.0000 | 0.0000 | 0.6160 | 0.7880 |
| 5522 | 0.0320 | 0.6960 | 32.0000 | 0.0000 | 0.5300 | 0.8480 |
| 709 | 0.0341 | 0.7000 | 29.8000 | 0.0000 | 0.4970 | 0.8680 |
| 5507 | 0.0320 | 0.7040 | 38.0000 | 0.0000 | 0.6160 | 0.7880 |
| 5523 | 0.0320 | 0.7040 | 32.0000 | 0.0000 | 0.5300 | 0.8480 |
| 5524 | 0.0337 | 0.7390 | 38.0000 | 0.0000 | 0.6160 | 0.7880 |
| 5525 | 0.0337 | 0.7390 | 32.0000 | 0.0000 | 0.5300 | 0.8480 |
| 5509 | 0.0338 | 0.7660 | 38.0000 | 0.0000 | 0.6160 | 0.7880 |
| 5526 | 0.0337 | 0.7660 | 32.0000 | 0.0000 | 0.5300 | 0.8480 |
| 5511 | 0.0339 | 0.7740 | 38.0000 | 0.0000 | 0.6160 | 0.7880 |
| 5527 | 0.0338 | 0.7740 | 32.0000 | 0.0000 | 0.5300 | 0.8480 |
| 710 | 0.0339 | 0.8000 | 29.8000 | 0.0000 | 0.4970 | 0.8680 |
| 726 | 0.0339 | 0.8000 | 37.7000 | 0.0000 | 0.6120 | 0.7910 |
| 5528 | 0.0337 | 0.8010 | 32.0000 | 0.0000 | 0.5300 | 0.8480 |
| 5529 | 0.0343 | 0.8090 | 32.0000 | 0.0000 | 0.5300 | 0.8480 |
| 5530 | 0.0337 | 0.8360 | 32.0000 | 0.0000 | 0.5300 | 0.8480 |
| 5531 | 0.0336 | 0.8440 | 32.0000 | 0.0000 | 0.5300 | 0.8480 |
| 711 | 0.0336 | 0.8700 | 29.8000 | 0.0000 | 0.4970 | 0.8680 |
| 727 | 0.0336 | 0.8700 | 37.7000 | 0.0000 | 0.6120 | 0.7910 |
| 5533 | 0.0335 | 0.8710 | 32.0000 | 0.0000 | 0.5300 | 0.8480 |
| 5534 | 0.0337 | 0.8790 | 38.0000 | 0.0000 | 0.6160 | 0.7880 |
| 5535 | 0.0338 | 0.8790 | 32.0000 | 0.0000 | 0.5300 | 0.8480 |
| 5536 | 0.0310 | 0.4590 | 27.0000 | 0.0000 | 0.4540 | 0.8910 |
| 5537 | 0.0310 | 0.4650 | 27.0000 | 0.0000 | 0.4540 | 0.8910 |
| 2055 | 0.0345 | 0.8400 | 45.0000 | 0.0000 | 0.7070 | 0.7070 |
| 2056 | 0.0345 | 0.8500 | 45.0000 | 0.0000 | 0.7070 | 0.7070 |
| 5538 | 0.0343 | 0.8440 | 27.0000 | 0.0000 | 0.4540 | 0.8910 |
| 5539 | 0.0341 | 0.8500 | 27.0000 | 0.0000 | 0.4540 | 0.8910 |
| 5253 | 0.0321 | 0.1750 | 18.0000 | -0.1800 | 0.3040 | 0.9360 |
| 5254 | 0.0323 | 0.2000 | 180.0000 | -0.1050 | 0.0000 | -0.9950 |
| 5257 | 0.0325 | 0.3100 | 270.0000 | 0.0000 | -1.0000 | 0.0000 |
| 5258 | 0.0315 | 0.3400 | 270.0000 | 0.0000 | -1.0000 | 0.0000 |
| 626 | 0.0320 | 0.4400 | 0.0000 | 0.0000 | 0.0000 | 1.0000 |
| 628 | 0.0310 | 0.4500 | 0.0000 | 0.0000 | 0.0000 | 1.0000 |
| 629 | 0.0310 | 0.4550 | 0.0000 | 0.0000 | 0.0000 | 1.0000 |
| 631 | 0.0300 | 0.4700 | 0.0000 | 0.0000 | 0.0000 | 1.0000 |
| 632 | 0.0310 | 0.4800 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| 633 | 0.0310 | 0.4900 | 0.0000 | 0.0000 | 0.0000 | 1.0000 |
| 634 | 0.0310 | 0.5000 | 0.0000 | 0.0000 | 0.0000 | 1.0000 |
| 648 | 0.0320 | 0.9260 | 0.0000 | 0.0000 | 0.0000 | 1.0000 |
| 696 | 0.0330 | 0.9260 | 17.0000 | 0.0000 | 0.2920 | 0.9560 |
| 712 | 0.0325 | 0.9260 | 29.8000 | 0.0000 | 0.4970 | 0.8680 |
| 893 | 0.0300 | 0.9000 | 315.0000 | 0.0000 | -0.7070 | 0.7070 |
| 895 | 0.0300 | 0.9260 | 315.0000 | 0.0000 | -0.7070 | 0.7070 |
| 2001 | 0.0300 | 0.5690 | 23.1000 | 0.0000 | 0.3920 | 0.9200 |
| 2002 | 0.0320 | 0.7030 | 23.1000 | 0.0000 | 0.3920 | 0.9200 |
| 2003 | 0.0300 | 0.8350 | 23.1000 | 0.0000 | 0.3920 | 0.9200 |
| 2004 | 0.0300 | 0.9000 | 20.0000 | 0.0000 | 0.3420 | 0.9400 |
| 2007 | 0.0300 | 0.5460 | 31.4300 | 0.0000 | 0.5210 | 0.8530 |
| 2008 | 0.0310 | 0.5810 | 31.4300 | 0.0000 | 0.5210 | 0.8530 |
| 2009 | 0.0325 | 0.6160 | 31.4300 | 0.0000 | 0.5210 | 0.8530 |

TABLE 3. Concluded

| | | | | | | |
|---|---|---|---|---|---|---|
| 2010 | 0.0330 | 0.6500 | 31.4300 | 0.0000 | 0.5210 | 0.8530 |
| 2035 | 0.0290 | 0.9350 | 326.1000 | 0.0000 | -0.5580 | 0.8300 |
| 2060 | 0.0300 | 0.8900 | 45.0000 | 0.0000 | 0.7070 | 0.7070 |
| 2064 | 0.0295 | 0.9350 | 45.0000 | 0.0000 | 0.7070 | 0.7070 |
| 2089 | 0.0300 | 0.9370 | 352.2000 | 0.0000 | -0.1360 | 0.9910 |
| 2114 | 0.0300 | 0.8300 | 305.4000 | 0.0000 | -0.8150 | 0.5790 |
| 2125 | 0.0300 | 0.9000 | 301.5000 | 0.0000 | -0.8530 | 0.5220 |
| 2140 | 0.0300 | 0.9260 | 289.4000 | 0.0000 | -0.9430 | 0.3320 |
| 2145 | 0.0295 | 0.9300 | 289.4000 | 0.0000 | -0.9430 | 0.3320 |
| 2146 | 0.0300 | 0.9300 | 270.0000 | 0.0000 | -1.0000 | 0.0000 |
| 2151 | 0.0285 | 0.9350 | 258.0000 | 0.0000 | -0.9780 | -0.2080 |
| 2158 | 0.0300 | 0.9260 | 335.2000 | 0.0000 | -0.4190 | 0.9080 |
| 2160 | 0.0300 | 0.9260 | 345.5000 | 0.0000 | -0.2500 | 0.9680 |
| 2161 | 0.0305 | 0.9260 | 305.0000 | 0.0000 | -0.8190 | 0.5740 |
| 3261 | 0.0322 | 0.0150 | 90.0000 | -0.3090 | -0.9511 | 0.0000 |
| 3066 | 0.5000 | 0.9460 | 48.0000 | -1.0000 | 0.0000 | 0.0000 |
| 3067 | 0.4420 | 0.9470 | 35.0000 | 0.0000 | -0.5736 | 0.8192 |
| 3068 | 0.4520 | 0.9460 | 42.0000 | -1.0000 | 0.0000 | 0.0000 |
| 3203 | 0.5280 | 0.7570 | 50.0000 | -1.0000 | 0.0000 | 0.0000 |
| 3207 | 0.5340 | 0.1450 | 270.0000 | -0.5000 | 0.8660 | 0.0000 |
| 5029 | 0.5250 | 0.0120 | 180.0000 | -0.6350 | 0.0000 | -0.7730 |
| 5032 | 0.6120 | 0.1871 | 180.0000 | -0.1440 | 0.0000 | -0.9900 |
| 5035 | 0.5700 | 0.3328 | 180.0000 | 0.0000 | 0.0000 | -1.0000 |
| 5036 | 0.5000 | 0.3328 | 251.4000 | 0.0000 | -0.9480 | -0.3190 |
| 5037 | 0.4780 | 0.3328 | 270.0000 | 0.0000 | -1.0000 | 0.0000 |
| 5038 | 0.4200 | 0.3328 | 288.6000 | 0.0000 | -0.9480 | 0.3190 |
| 5039 | 0.5040 | 0.4179 | 2.5000 | 0.0000 | 0.0440 | 0.9990 |
| 5040 | 0.5120 | 0.4103 | 2.5000 | 0.0000 | 0.0440 | 0.9990 |
| 5041 | 0.4920 | 0.4244 | 2.5000 | 0.0000 | 0.0440 | 0.9990 |
| 5042 | 0.5500 | 0.3515 | 25.0000 | 0.0000 | 0.4230 | 0.9060 |
| 5043 | 0.5600 | 0.3831 | 270.0000 | 0.0000 | -1.0000 | 0.0000 |
| 5044 | 0.5800 | 0.4090 | 180.0000 | 0.0000 | 0.0000 | -1.0000 |
| 5241 | 0.5650 | 0.0560 | 31.3100 | -0.8240 | 0.2960 | 0.4830 |
| 5259 | 0.5640 | 0.4730 | 37.5000 | 0.0000 | 0.6090 | 0.7830 |
| 5260 | 0.4460 | 0.4710 | 35.0000 | 0.0000 | 0.5740 | 0.8190 |
| 5053 | 0.5340 | 0.3690 | 23.0000 | -0.4300 | -0.7970 | 0.4240 |
| 5054 | 0.4840 | 0.3620 | 25.0000 | -0.6000 | 0.3380 | 0.7250 |
| 5055 | 0.4880 | 0.5500 | 37.5000 | 0.0000 | 0.6090 | 0.7930 |
| 5056 | 0.5120 | 0.8440 | 37.5000 | 0.0000 | 0.6090 | 0.7930 |
| 5057 | 0.5180 | 0.4460 | 0.0000 | -1.0000 | 0.0000 | 0.0000 |
| 5058 | 0.4860 | 0.3328 | 270.0000 | -1.0000 | 0.0000 | 0.0000 |
| 5059 | 0.4440 | 0.4070 | 320.0000 | -0.4820 | 0.0000 | 0.8760 |
| 5060 | 0.5200 | 0.9370 | 17.0000 | -1.0000 | 0.0000 | 0.0000 |
| 5181 | 0.5500 | 0.0560 | 37.7000 | -0.7350 | 0.4150 | 0.5370 |
| 5061 | 0.4620 | 0.9310 | 330.0000 | -1.0000 | 0.0000 | 0.0000 |
| 5062 | 0.5120 | 0.9070 | 25.0000 | -1.0000 | 0.0000 | 0.0000 |
| 5540 | 0.5120 | 0.8500 | 32.0000 | 0.0000 | 0.5300 | 0.8980 |
| 5242 | 0.5100 | 0.0400 | 180.0000 | -0.5870 | 0.0000 | 0.0000 |
| 3243 | 0.4120 | 0.0000 | 90.0000 | -1.0000 | 0.0000 | 0.0000 |

TABLE 4. Schmidt-Boelter Gage Calibration Constants

GAGE SENSITIVITY TO INCIDENT RADIANT FLUX

(ABSORPTIVITY = 0.97)

| GAGE | $C_1$ SENSITIVITY mv/BTU/ft$^2$-sec | GAGE | $C_1$ SENSITIVITY mv/BTU/ft$^2$-sec |
|---|---|---|---|
| 3066 | 0.500 | 5053 | 0.534 |
| 3067 | 0.442 | 5054 | 0.484 |
| 3068 | 0.452 | 5055 | 0.488 |
| 3203 | 0.528 | 5056 | 0.512 |
| 3207 | 0.534 | 5057 | 0.518 |
| 3243 | 0.412 | 5058 | 0.486 |
| 5029 | 0.525 | 5059 | 0.444 |
| 5032 | 0.612 | 5060 | 0.520 |
| 5035 | 0.570 | 5061 | 0.462 |
| 5036 | 0.500 | 5062 | 0.512 |
| 5037 | 0.478 | 5181 | 0.550 |
| 5038 | 0.420 | 5241 | 0.565 |
| 5039 | 0.504 | 5242 | 0.510 |
| 5040 | 0.512 | 5259 | 0.564 |
| 5041 | 0.492 | 5260 | 0.446 |
| 5042 | 0.550 | 5540 | 0.512 |
| 5043 | 0.560 | | |
| 5044 | 0.580 | | |

34

VKF TUNNEL C (M=4) TEST LOG TABLE 5. Run Summary



| USER | PROJECT TITLE | PROJECT | DATE |
|---|---|---|---|
| NASA MARSHALL / AEDC DOFA | NASA / AEDC E.T. INTERFERENCE HTG. TEST | C795VC (V--C-2E) | |
| REPRESENTATIVE(S): JOHN WARMBROD, TOM BEST | MODEL: 0.0175 SCALE 60-OTS | TEST PERSONNEL: W. K. CRAIN, K. W. NUTT | |

| Run | Configuration Code | RE/FT $\times 10^{6}$ | M | PT psia | TT °F | ALPHA deg | BETA deg | DELTA E deg | DELT BF deg | DELT SB deg | | Time | Remarks |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 86 | OTS+Tr+TVC | 4.0 | 4.0 | 174 | 980 | 0 | 0 | 0 | 0 | 0 | | | |
| 87 | | | | | | | 3 | | | | | | |
| 88 | | | | | | | -3 | | | | | | |
| 89 | | | | | | 5 | 0 | | | | | | |
| 90 | | | | | | | 3 | | | | | | |
| 91 | | | | | | | -3 | | | | | | |
| 92 | | | | | | -5 | 0 | | | | | | |
| 93 | | | | | | | 3 | | | | | | |
| 94 | | | | | | | -3 | | | | | | |
| 95 | | | | | | 0 | 0 | | | | | | |
| 96 | OTS + TVC | 0.5 | | 20 | 980 | 0.7 | -0.6 | | | | | | TRIPS OFF SRB's |
| | | | | | | | | | | | | | |
| 97 | OTS+Tr+TVC | 4.0 | | 140 | 790 | 0 | 0 | | | | | | TRIPS ON SRB's |
| 98 | | | | 120 | 590 | | | | | | | | |
| 99 | | | | 108 | 490 | | | | | | | | |
| | | | | | | | | | | | | | |
| 100 | | 4.0 | | 60 | 280 | 0 | 0 | | | | | | |
| 101 | | | | | | 5 | | | | | | | |
| 102 | | | | | | -5 | | | | | | | |
| | | | | | | | | | | | | | |

NOMENCLATURE

VKF TUNNEL C(M=4) TEST LOG

TABLE 5. Concluded



| USER | PROJECT TITLE | PROJECT | DATE |
|---|---|---|---|
| NASA MARSHALL /AEDC DOFA | NASA/AEDC E.T. INTERFERENCE HTG. TEST | C795VC (V--C-2E) | |
| REPRESENTATIVE(S): JOHN WARMBROD, TOM BEST | MODEL: 0.0175 SCALE 60-OTS | TEST PERSONNEL: W.K. CRAIN, K.W. NUTT | |

| Run | Configuration Code | RE/FT X10^-6 | M | PT psia | TT °F | ALPHA deg | BETA deg | DELTA E deg | DELT BF deg | DELT SB deg | | Time | Remarks |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 103 | OTS+Tr+TVC | 4.0 | 4.0 | 60 | 280 | -5 | 3 | 0 | 0 | 0 | | | |
| 104 | ↓ | ↓ | ↓ | ↓ | ↓ | ↓ | -3 | ↓ | ↓ | ↓ | | | |
| 105 | ↓ | ↓ | ↓ | ↓ | ↓ | 0 | 0 | ↓ | ↓ | ↓ | | | |
| | ↓ | | ↓ | | ↓ | | | ↓ | ↓ | ↓ | | | |
| 106 | ↓ | 6.8 | ↓ | 120 | ↓ | 0.7 | -0.6 | ↓ | ↓ | ↓ | | | |
| 107 | ↓ | ↓ | ↓ | ↓ | ↓ | ↓ | ↓ | ↓ | ↓ | ↓ | | | REPEAT OF RUN 106 |

NOMENCLATURE



GC-184 (SUPERSEDES VB-2) 3/81

APSC Arnold AFSC Tenn

TABLE 6. Photographic Summary

| Camera | View | Camera Type | Type Photography | Roll No. | Run. No. |
|---|---|---|---|---|---|
| 1 | Fwd Port Operating Side | Varitron 70 mm | Shadowgraph Stills | 0293<br>0298 | 86-95<br>97-107 |
| | | | Color Schlieren Stills | 0364 | 96 |
| 2. | Aft Port Operating Side | | Shadowgraph Stills | 0294<br>0299 | 86-95<br>97-107 |
| | | | Color Schlieren Stills | 0366 | 96 |

## APPENDIX III

### REFERENCE HEAT-TRANSFER COEFFICIENTS

In presenting heat-transfer coefficient results it is convenient to use reference coefficients to normalize the data. Equilibrium stagnation point values derived from the work of Fay and Riddell* were used to normalize the data obtained in this test. These reference coefficients are given by:

$$H(REF) = \frac{8.17173(PT2)^{1/2}(MUTT)^{0.4}\left[1 - \frac{P}{PT2}\right]^{0.25}\left[0.2235 + (1.35 \times 10^{-5})(TT+560)\right]}{(RN)^{1/2}(TT)^{0.15}}$$

and

$$STFR = \frac{H(REF)}{(RHO)(V)\left[0.2235 + (1.35 \times 10^{-5})(TT + 560)\right]}$$

where

| | |
|---|---|
| PT2 | Stagnation pressure downstream of a normal shock wave, psia |
| MUTT | Air viscosity based on TT, $lb_f$-sec/ft$^2$ |
| P | Free-stream pressure, psia |
| TT | Tunnel stilling chamber temperature, °R |
| RN | Reference nose radius, (0.0175 ft or 0.04 ft determined by model scale) |
| RHO | Free-stream density, lbm/ft$^3$ |
| V | Free-stream velocity, ft/sec |

*Fay, J. A. and Riddell, F. R. "Theory of Stagnation Point Heat Transfer in Dissociated Air," Journal of the Aeronautical Sciences, Vol. 25, No. 2, February 1958.

# APPENDIX IV

## SAMPLE TABULATED DATA

ARNOLD AIR FORCE STATION, TENNESSEE
NASA/RI IH97 HEATING TEST
PAGE 2

21-OCT-82
TIME RECORD 13:34:27
PROJECT NUMBER V4 C-2E

| RUN | PHASE | MODEL | MACH NO | PT,PSIA | TT,DEGR | ALPHA-SECTOR | ROLL-SECTOR | ALPHA | YAW |
|---|---|---|---|---|---|---|---|---|---|
| 88 | C | 60-OTS | 4.00 | 174.6 | 1440.7 | 3.07 | -90.03 | -0.00 | 2.95 |

| T (DEGR) | P (PSIA) | Q (PSIA) | V (FT/SEC) | RHO (LBM/FT3) | MU (LB-SEC/FT2) | RE (FT-1) | H(REF) (RN= .0175FT) | STFR (RN= .0175FT) | DELTAE | DELTBF | DELTSB |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 351.43 | 1.127 | 12.622 | 3676. | 8.655E-03 | 2.719E-07 | 3.637E+06 | 8.931E-02 | 1.120E-02 | 0. | 0. | 0. |

| TC NO | TW (DEGR) | DTW/DT (DEG/S) | QDOT (BTU/FT2-S) | H(TT) (BTU/FT2-S-DEGR) | H(TT) /HREF | H(.95TT) (BTU/FT2-S-DEGR) | H(.95TT) /HREF | R | H(RTT) BTU/FT2-S-DEGR) | H(RTT) /HREF | THERMOCOUPLE LOCATIONS X/L | THETA | SKIN THICKNESS (IN) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 5250 | 665.6 | 155.106 | 2.217E+01 | 2.860E-02 | 0.3203 | 3.1534E-02 | 0.3531 | 0.922 | 3.3453E-02 | 0.3746 | 0.444 | 358.000 | 0.030 |
| 5251 | 576.6 | 64.763 | 9.160E+00 | 1.060E-02 | 0.1187 | 1.1566E-02 | 0.1295 | 0.922 | 1.2186E-02 | 0.1365 | 0.630 | 352.500 | 0.031 |
| 5252 | 574.5 | 69.091 | 1.043E+01 | 1.204E-02 | 0.1349 | 1.3136E-02 | 0.1471 | 0.922 | 1.3835E-02 | 0.1549 | 0.837 | 310.000 | 0.033 |
| | | | | | | | | | | | ET SOFI PLUG LOCATIONS | | |
| 5156 | 668.5 | 161.473 | 2.550E+01 | 3.302E-02 | 0.3698 | 3.6419E-02 | 0.4078 | 0.945 | 3.6809E-02 | 0.4122 | 0.051 | 25.000 | 0.033 |
| 699 | 674.4 | 109.444 | 1.707E+01 | 2.228E-02 | 0.2494 | 2.4588E-02 | 0.2753 | 0.945 | 2.4859E-02 | 0.2783 | 0.050 | 29.800 | 0.033 |
| 715 | 687.4 | 176.541 | 2.771E+01 | 3.678E-02 | 0.4119 | 4.0671E-02 | 0.4554 | 0.944 | 4.1165E-02 | 0.4609 | 0.050 | 37.700 | 0.033 |
| 5158 | 639.2 | 141.290 | 2.180E+01 | 2.720E-02 | 0.3046 | 2.9891E-02 | 0.3347 | 0.938 | 3.0627E-02 | 0.3429 | 0.081 | 25.000 | 0.033 |
| 5159 | 614.1 | 116.304 | 1.773E+01 | 2.145E-02 | 0.2402 | 2.3499E-02 | 0.2631 | 0.936 | 2.4164E-02 | 0.2706 | 0.091 | 25.000 | 0.033 |
| 5160 | 632.5 | 136.619 | 2.563E+01 | 3.171E-02 | 0.3551 | 3.4815E-02 | 0.3898 | 0.922 | 3.6834E-02 | 0.4124 | 0.480 | 17.000 | 0.040 |
| 5162 | 644.8 | 139.309 | 2.096E+01 | 2.634E-02 | 0.2949 | 2.8960E-02 | 0.3243 | 0.922 | 3.0669E-02 | 0.3434 | 0.447 | 20.000 | 0.032 |
| 5173 | 560.1 | 31.007 | 4.728E+00 | 5.370E-03 | 0.0601 | 5.8481E-03 | 0.0655 | 0.922 | 6.1552E-03 | 0.0689 | 0.861 | 20.000 | 0.034 |
| | | | | | | | | | | | EXTERNAL TANK SLA REGION | | |
| 5072 | 561.2 | 75.474 | 1.367E+01 | 1.554E-02 | 0.1740 | 1.6928E-02 | 0.1895 | 0.922 | 1.7810E-02 | 0.1994 | 0.290 | 280.000 | 0.040 |
| 5073 | 606.5 | 147.282 | 2.728E+01 | 3.270E-02 | 0.3661 | 3.5790E-02 | 0.4007 | 0.922 | 3.7772E-02 | 0.4229 | 0.300 | 280.000 | 0.040 |
| 5074 | 649.6 | 196.258 | 3.712E+01 | 4.692E-02 | 0.5253 | 5.1617E-02 | 0.5780 | 0.922 | 5.4657E-02 | 0.6120 | 0.310 | 280.000 | 0.040 |
| 5075 | 657.8 | 196.522 | 3.731E+01 | 4.766E-02 | 0.5337 | 5.2495E-02 | 0.5878 | 0.922 | 5.5624E-02 | 0.6228 | 0.320 | 280.000 | 0.040 |
| 5076 | 647.7 | 184.930 | 3.494E+01 | 4.407E-02 | 0.4935 | 4.8473E-02 | 0.5428 | 0.922 | 5.1320E-02 | 0.5746 | 0.330 | 280.000 | 0.040 |
| 5077 | 679.8 | 218.109 | 4.185E+01 | 5.500E-02 | 0.6158 | 6.0751E-02 | 0.6802 | 0.922 | 6.4495E-02 | 0.7222 | 0.340 | 280.000 | 0.040 |
| 5078 | 671.1 | 213.987 | 4.089E+01 | 5.313E-02 | 0.5950 | 5.8621E-02 | 0.6564 | 0.922 | 6.2187E-02 | 0.6963 | 0.350 | 280.000 | 0.040 |
| 5079 | 625.9 | 156.893 | 2.934E+01 | 3.601E-02 | 0.4032 | 3.9498E-02 | 0.4423 | 0.922 | 4.1745E-02 | 0.4674 | 0.360 | 280.000 | 0.040 |
| 5080 | 565.0 | 84.056 | 1.525E+01 | 1.742E-02 | 0.1950 | 1.8979E-02 | 0.2125 | 0.922 | 1.9972E-02 | 0.2236 | 0.370 | 280.000 | 0.040 |
| 5081 | 575.5 | 95.130 | 1.735E+01 | 2.006E-02 | 0.2246 | 2.1878E-02 | 0.2450 | 0.922 | 2.3040E-02 | 0.2580 | 0.385 | 280.000 | 0.040 |
| 5082 | 548.8 | 59.644 | 1.073E+01 | 1.204E-02 | 0.1348 | 1.3095E-02 | 0.1466 | 0.922 | 1.3771E-02 | 0.1542 | 0.395 | 337.500 | 0.040 |
| 5083 | 591.9 | 91.291 | 1.280E+01 | 1.508E-02 | 0.1689 | 1.6479E-02 | 0.1845 | 0.922 | 1.7381E-02 | 0.1946 | 0.470 | 337.500 | 0.031 |
| 5084 | 586.4 | 84.928 | 1.198E+01 | 1.390E-02 | 0.1557 | 1.5181E-02 | 0.1700 | 0.922 | 1.6006E-02 | 0.1792 | 0.500 | 337.500 | 0.031 |
| 5085 | 545.3 | 55.297 | 9.935E+00 | 1.110E-02 | 0.1242 | 1.2067E-02 | 0.1351 | 0.922 | 1.2687E-02 | 0.1421 | 0.395 | 330.000 | 0.040 |
| 5086 | 562.0 | 66.442 | 1.216E+01 | 1.416E-02 | 0.1585 | 1.5455E-02 | 0.1731 | 0.922 | 1.6288E-02 | 0.1824 | 0.431 | 330.000 | 0.040 |
| 5087 | 541.0 | 43.784 | 7.849E+00 | 8.724E-03 | 0.0977 | 9.4835E-03 | 0.1062 | 0.922 | 9.9690E-03 | 0.1116 | 0.395 | 343.120 | 0.040 |
| 5088 | 560.8 | 45.643 | 8.265E+00 | 9.393E-03 | 0.1052 | 1.0231E-02 | 0.1146 | 0.922 | 1.0769E-02 | 0.1206 | 0.390 | 40.000 | 0.040 |
| 5096 | 584.1 | 60.926 | 8.357E+00 | 9.757E-03 | 0.1092 | 1.0653E-02 | 0.1193 | 0.922 | 1.1230E-02 | 0.1257 | 0.550 | 17.000 | 0.030 |
| 5097 | 585.7 | 59.208 | 8.141E+00 | 9.521E-03 | 0.1066 | 1.0397E-02 | 0.1164 | 0.922 | 1.0962E-02 | 0.1227 | 0.550 | 11.800 | 0.030 |
| 635 | 592.0 | 75.826 | 1.028E+01 | 1.212E-02 | 0.1357 | 1.3242E-02 | 0.1483 | 0.922 | 1.3967E-02 | 0.1564 | 0.550 | 0.000 | 0.029 |
| 5099 | 592.9 | 86.715 | 1.177E+01 | 1.388E-02 | 0.1554 | 1.5169E-02 | 0.1698 | 0.922 | 1.6001E-02 | 0.1792 | 0.550 | 348.000 | 0.029 |
| 5100 | 579.7 | 65.252 | 8.796E+00 | 1.022E-02 | 0.1144 | 1.1149E-02 | 0.1248 | 0.922 | 1.1749E-02 | 0.1316 | 0.550 | 337.500 | 0.029 |
| 5101 | 556.2 | 72.752 | 1.067E+01 | 1.249E-02 | 0.1399 | 1.3640E-02 | 0.1527 | 0.922 | 1.4382E-02 | 0.1610 | 0.625 | 17.000 | 0.032 |
| 5102 | 578.8 | 57.825 | 8.452E+00 | 9.806E-03 | 0.1098 | 1.0701E-02 | 0.1198 | 0.922 | 1.1276E-02 | 0.1263 | 0.625 | 11.800 | 0.032 |
| 5103 | 573.3 | 54.056 | 7.879E+00 | 9.085E-03 | 0.1017 | 9.9073E-03 | 0.1109 | 0.922 | 1.0437E-02 | 0.1169 | 0.625 | 0.000 | 0.032 |
| 5104 | 577.7 | 66.235 | 9.374E+00 | 1.086E-02 | 0.1216 | 1.1852E-02 | 0.1327 | 0.922 | 1.2488E-02 | 0.1398 | 0.625 | 348.000 | 0.031 |
| 5105 | 565.3 | 52.902 | 7.320E+00 | 8.363E-03 | 0.0936 | 9.1123E-03 | 0.1020 | 0.922 | 9.5934E-03 | 0.1074 | 0.625 | 337.500 | 0.031 |

Sample 1. Thin Skin Thermocouple

ARNOLD AIR FORCE STATION, TENNESSEE
NASA/RI 1497 HEATING TEST
PAGE 6

TIME RE  JED 13:34:27
PROJEC  JMBER V4 C-2E

| RUN | PHASE | MODEL | MACH NO | PT,PSIA | TT,DEGR | ALPHA-SECTOR | ROLL-SECTOR | ALPHA | YAW |
|---|---|---|---|---|---|---|---|---|---|
| 88 | C | 60-OTS | 4.00 | 174.6 | 1440.7 | 3.07 | -90.03 | -0.00 | 2.95 |

| T (DEGR) | P (PSIA) | Q (PSIA) | V (FT/SEC) | RHO (LBM/FT3) | MU (LB-SEC/FT2) | RE (FT-1) | H(REF) (RN= .0175FT) | STFR (RN= .0175FT) | DELTAE | DELTBF | DELTSB |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 351.43 | 1.127 | 12.622 | 3676. | 8.655E-03 | 2.719E-07 | 3.637E+06 | 8.931E-02 | 1.120E-02 | 0. | 0. | 0. |

| GAGE NO | TW (DEGR) | QDOT (BTU/FT2-S) | H(TT) (BTU/FT2-S-DEGR) | H(TT) /HREF | H(.95TT) (BTU/FT2-S-DEGR) | H(.95TT) /HREF | R | H(RTT) BTU/FT2-S-DEGR) | H(RTT) /HREF | THERMOCOUPLE LOCATIONS X/L | THETA | SKIN THICKNESS (IN) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 3066 | 557.8 | 4.082E+00 | 4.623E-03 | 0.0518 | 5.0342E-03 | 0.0564 | 1.000 | 4.6251E-03 | 0.0518 | 0.946 | 48.000 | |
| 3067 | 583.5 | 3.444E+00 | 4.018E-03 | 0.0450 | 4.3862E-03 | 0.0491 | 0.922 | 4.6230E-03 | 0.0518 | 0.947 | 35.000 | |
| 3068 | 628.0 | 4.772E+00 | 5.872E-03 | 0.0658 | 6.4436E-03 | 0.0722 | 1.000 | 5.8747E-03 | 0.0658 | 0.946 | 42.000 | |
| 3203 | 887.8 | 3.788E+01 | 6.850E-02 | 0.7671 | 7.8767E-02 | 0.8820 | 1.000 | 6.8544E-02 | 0.7675 | 0.757 | 50.000 | |
| 3207 | 645.7 | 2.272E+01 | 2.858E-02 | 0.3201 | 3.1433E-02 | 0.3520 | 0.938 | 3.2173E-02 | 0.3603 | 0.145 | 270.000 | |
| | | | | | | | | | | ET DFI LOCATIONS | | |
| 5029 | 650.7 | 3.617E+01 | 4.579E-02 | 0.5128 | 5.0390E-02 | 0.5642 | 0.954 | 5.0002E-02 | 0.5599 | 0.012 | 180.000 | |
| 5032 | 556.9 | 9.143E+00 | 1.035E-02 | 0.1158 | 1.1264E-02 | 0.1261 | 0.924 | 1.1815E-02 | 0.1323 | 0.187 | 180.000 | |
| 5035 | 522.6 | 4.095E+00 | 4.460E-03 | 0.0499 | 4.8399E-03 | 0.0542 | 0.922 | 5.0823E-03 | 0.0569 | 0.333 | 180.000 | |
| 5036 | 625.5 | 2.619E+01 | 3.213E-02 | 0.3598 | 3.5246E-02 | 0.3947 | 0.922 | 3.7252E-02 | 0.4171 | 0.333 | 251.400 | |
| 5037 | 713.4 | 3.592E+01 | 4.939E-02 | 0.5531 | 5.4823E-02 | 0.6139 | 0.922 | 5.8385E-02 | 0.6538 | 0.333 | 270.000 | |
| 5038 | 665.4 | 2.758E+01 | 3.557E-02 | 0.3983 | 3.9211E-02 | 0.4391 | 0.922 | 4.1577E-02 | 0.4655 | 0.333 | 288.600 | |
| 5039 | 585.5 | 1.351E+01 | 1.579E-02 | 0.1768 | 1.7245E-02 | 0.1931 | 0.922 | 1.8182E-02 | 0.2036 | 0.418 | 2.500 | |
| 5040 | 573.8 | 1.062E+01 | 1.225E-02 | 0.1372 | 1.3364E-02 | 0.1496 | 0.922 | 1.4078E-02 | 0.1576 | 0.410 | 2.500 | |
| 5041 | 613.5 | 1.643E+01 | 1.987E-02 | 0.2225 | 2.1765E-02 | 0.2437 | 0.922 | 2.2994E-02 | 0.2575 | 0.424 | 2.500 | |
| 5042 | 526.0 | 2.219E+00 | 2.427E-03 | 0.0272 | 2.6341E-03 | 0.0295 | 0.922 | 2.7665E-03 | 0.0310 | 0.352 | 25.000 | |
| 5043 | 543.8 | 5.548E+00 | 6.186E-03 | 0.0693 | 6.7258E-03 | 0.0753 | 0.922 | 7.0684E-03 | 0.0791 | 0.383 | 270.000 | |
| 5044 | 522.9 | 3.797E+00 | 4.137E-03 | 0.0463 | 4.4892E-03 | 0.0503 | 0.922 | 4.7140E-03 | 0.0528 | 0.409 | 180.000 | |
| 5241 | -1944.6 | 3.540E+01 | 1.046E-02 | 0.1171 | 1.0683E-02 | 0.1196 | 0.973 | 1.0576E-02 | 0.1184 | 0.056 | 31.310 | |
| 5259 | 649.6 | 3.734E+00 | 4.720E-03 | 0.0528 | 5.1928E-03 | 0.0581 | 0.922 | 5.5014E-03 | 0.0616 | 0.473 | 37.500 | |
| 5260 | 561.8 | 2.264E+01 | 2.636E-02 | 0.2952 | 2.8776E-02 | 0.3222 | 0.922 | 3.0331E-02 | 0.3396 | 0.471 | 35.000 | |
| 5053 | 591.6 | 9.473E+00 | 1.116E-02 | 0.1249 | 1.2192E-02 | 0.1365 | 0.940 | 1.2426E-02 | 0.1391 | 0.369 | 23.000 | |
| 5054 | 664.6 | 2.593E+01 | 3.341E-02 | 0.3741 | 3.6832E-02 | 0.4124 | 0.949 | 3.6920E-02 | 0.4134 | 0.362 | 25.000 | |
| 5055 | 596.7 | 5.383E+00 | 6.378E-03 | 0.0714 | 6.9734E-03 | 0.0781 | 0.922 | 7.3579E-03 | 0.0824 | 0.540 | 37.500 | |
| 5056 | 613.8 | 1.228E+00 | 1.485E-03 | 0.0166 | 1.6268E-03 | 0.0182 | 0.922 | 1.7186E-03 | 0.0192 | 0.856 | 37.500 | |
| 5057 | 578.7 | 3.861E+01 | 4.479E-02 | 0.5015 | 4.8873E-02 | 0.5472 | 1.000 | 4.4805E-02 | 0.5017 | 0.435 | 0.000 | |
| 5058 | 327.9 | 4.115E+01 | 3.698E-02 | 0.4141 | 3.9538E-02 | 0.4427 | 1.000 | 3.6989E-02 | 0.4142 | 0.333 | 270.000 | |
| 5059 | 819.6 | 1.787E+01 | 2.877E-02 | 0.3221 | 3.2542E-02 | 0.3644 | 0.941 | 3.3370E-02 | 0.3737 | 0.482 | 320.000 | |
| 5060 | 723.2 | -2.871E+01 | -4.002E-02 | -0.4481 | -4.4482E-02 | -0.4981 | 1.000 | -4.0034E-02 | -0.4483 | 0.937 | 17.000 | |
| 5181 | 731.7 | 3.224E+01 | 4.548E-02 | 0.5092 | 5.0619E-02 | 0.5668 | 0.962 | 4.9282E-02 | 0.5518 | 0.056 | 37.700 | |
| 5061 | 723.3 | 3.324E+01 | 4.633E-02 | 0.5188 | 5.1501E-02 | 0.5767 | 1.000 | 4.6350E-02 | 0.5190 | 0.931 | 330.000 | |
| 5062 | 1036.6 | 2.248E+01 | 5.563E-02 | 0.6229 | 6.7701E-02 | 0.7581 | 1.000 | 5.5676E-02 | 0.6234 | 0.907 | 25.000 | |
| 5540 | 540.1 | 6.914E-02 | 7.678E-05 | 0.0009 | 8.3454E-05 | 0.0009 | 0.922 | 8.7726E-05 | 0.0010 | 0.850 | 32.000 | |
| 5242 | 772.7 | 3.307E+01 | 4.951E-02 | 0.5544 | 5.5495E-02 | 0.6214 | 0.949 | 5.5588E-02 | 0.6224 | 0.040 | 180.000 | |
| 3243 | 653.1 | 4.854E+01 | 6.163E-02 | 0.6901 | 6.7836E-02 | 0.7596 | 1.000 | 6.1657E-02 | 0.6904 | 0.000 | 90.000 | |

Sample 2. Schmidt Boelter Gage